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IMPROVEMENTS IN THE VALUE AND CONSISTENCY OF CANOLA MEAL

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Saskatchewan Canola Development Commission
and the Canola Council of Canada
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Project Title: "**Improvements in the value and consistency of canola meal**".

1. Abstract/Summary

Research to assist the Canola industry produce a higher valued, more consistent meal product has been conducted. Samples of meal were collected on a routine basis and assessed for quality. Reports and recommendations were provided to the canola crushing companies. The conditions necessary to produce non-toasted meals were defined and meal was successfully produced for animal feeding studies. Toasted and non-toasted meals have been compared in a production trial with 3240 broiler chickens and the results indicate the non-toasted meal is superior and may be produced at a lower cost than toasted meals. Toasted and non-toasted meals have also been produced to determine if toasted is required for optimal swine and dairy production. Methods of determining digestible amino acid content in *in-vitro* were studied and show some promise. It was concluded that non-toasted meal can be produced commercially but some modifications to existing plants would be required.

2. Executive Summary

Canola meal comprises approximately 60% of the seed and is sold as a protein source for animal feeds. Typically the meal sells at a discount relative to other protein sources due to lower amino acid availability and a higher level of variability. This discount represents a loss of approximately $27 million dollars annually to the Saskatchewan economy. The objective of this project was to assist the canola crushing industry in western Canada produce a more consistent, higher valued meal product by collecting and analyzing samples on a routine basis. Samples were collected, and analyzed for content and digestibility of amino acids. Individual results were reported to crushing plants and recommendations made as how to produce higher quality or non-toasted meals. Digestibility and content of amino acids in the canola meal samples collected appeared to increase initially, but the quality suffered when the price of canola oil dropped and production was decreased accordingly. It appears that meal quality is somewhat dependent on production level in the plant. If the plant is running well below the designed capacity, the meal resides in the desolventizer for an abnormally long period of time and it is overcooked as a result. Therefore, it is recommended that if toasting continues to be the standard practice, that plant maintain

production at capacity or that the systems be modified so residence time in the desolventizer is controlled by variable speed rotary valves. The conditions to produce non-toasted canola meal and the effects of eliminating the toasting on broiler performance were also studied. The toasting or browning process appears to be primarily the result of added moisture during desolventization in the form of direct heat (sparge steam). Desolventization with only indirect heat results in light yellow colored meal instead of the standard brown colored meal and amino acid content and digestibility is improved. There were no adverse affects of eliminating the toasting process on broiler performance, in fact toasting impaired broiler performance. Toasted and non-toasted canola meals were produced for studies in swine and dairy to determine if there is a need for toasting for those species. Based on the poultry data, it appears there are no heat labile toxic factors in canola meal that need to be removed by the toasting process. Dr. Ruurd Zilstra at the Prarie Swine Centre and Dr. Dave Christensen are conducting the swine and Dairy studies, respectively, and will be reporting the findings in their future ADF reports. An astringent compound found in low temperature desolventized meal was ilsolated and identified as 4-pentene nitrile. This breakdown product of 3 butenyl glucosinolate as well as 41 other nitrile compounds are being recycled with the hexane and could contaminate the meal. These nitrile compounds were collected from a crushing plant, concentrated and fed to broiler chickens to measure the effects on performance. The nitriles had no effect on performance indicating they would not cause a problem in non-toasted canola meal. These compounds are not well defined and may have industrial or feed applications and should be studied further. The data on causes of toasting and the effects on meal quality were discussed with Crown Iron Works engineers, the company that manufactured most of the desolventization equipment currently in use in Canada. Based on those discussions methods of producing non-toasted canola meal are described and considered. The simplest method of producing a non-toasted canola meal would likely be to apply a vacuum to the desolventizer in stead of sparge steam. This would reduce both moisture content of the meal and the temperature at which the meal is desolventized, therefore eliminating the toasting process. It is not known what exact effect eliminating toasting will have on processing cost but it would appear to reduce them as the meal will not require drying after desolventization and the amount of heat applied to the meal is reduced.

This progress report consists of several individual technical reports that discuss various aspects of the research program on canola meal quality. A table of contents is provided below with a list of the reports included. All the milestones in the initial proposal have been met and the findings communicated to the industry for application.

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SURVEYS OF CANOLA MEAL QUALITY FROM WESTERN CANADIAN CRUSHING PLANTS

INTRODUCTION

Canola meal is a good source of protein with an excellent balance of amino acids, however, the digestibility is not as high or as consistent as soybean meal and therefore the meal trades at a relative discount. The meal contains approximately 75% of the protein of soybean meal but trades for 55-65% of the price. The objective of the research being conducted by the author is to assist the canola industry produce the highest quality meal possible though a monitoring program. A second objective is to collect and analyze enough samples *in-vivo* that *in-vitro* methods such as NIRS can be effectively calibrated to predict available amino acid content.

MATERIALS AND METHODS

Forty seven samples of commercial canola meal were collected from canola crushing plants located in western Canada over the period of two years and analyzed for amino acid content and apparent ileal digestibility in broiler chickens as described by Kadim and Moughan (1997). The assay consisted of raising broiler chickens to 14 days of age on a commercial starter diet, then providing experimental diets to 4 pens (replications) of 12 birds. The diets were semi-purified with canola meal being the only source of protein in the diet. At 24 days of age the birds were killed and the contents of the distal ileum collected. The digesta from all the birds in each replicate (up to 12 birds) was pooled and freeze dried prior to analysis for amino acid content and indigestible marker.

RESULTS AND DISCUSSION

Reports to Canola Crushing Plants

One of the objectives of this study was to assist the canola crushing companies to produce higher quality canola meal. Canola meal samples were collected from the plants every few months, analysed for apparent ileal digestibility and amino acid content. A series of reports were prepared and sent to the crushing plants detailing the quality of the meals collected from their plant in relation to other meals collected and to non-toasted meal. Recommendations were made as how to make a better quality meal and additional samples were requested after they adopted changes as recommended. The reports were also discussed with plant managers and staff either on site or over the phone to ensure the information was understood and to answer any questions that may have arisen. The digestibility and proportion of amino acids in canola meal are shown in Tables 1 and 2.

Amino acid analysis for these studies was conducted by Degussa-Hulls Ltd. in exchange for access to the digestibility data that produced as a result. An additional 16 canola meal samples were collected in June and fed to broiler chickens for determination of ileal amino acid digestibility, however, due to cutbacks and the elimination of an amino acid laboratory the amino acid content of the digesta and meals has not been reported back to the authors at the time of the writing of this report so digestibility values are not yet

available on those samples. When the remaining analyses are completed by Degussa, a final set of reports will be sent to the plants.

Application of Recommendations to Crushing Plants

Plant managers were pleased to receive the information and sent samples as often as possible but they indicated that there were some practical challenges to producing higher quality meal. The most frequent concern was that of potential losses of hexane. One of the primary purposes of the desolventizer/toaster is to recover hexane and most were concerned that additional hexane may be lost if the conditions are altered.

Hexane losses are a valid concern for the industry. Hexane is a volatile organic compound that may have long term negative impacts on the environment. In addition, hexane is a flammable compound and if high enough levels are found in the final products, there can be a safety issue as well. As a result, hexane recovery rates in the crushing plants are monitored closely. Unfortunately, a number of the plants do not have the ability to measure residual hexane levels in canola meals and therefore have no way of monitoring losses of hexane through meal. The authors obtained a portable gas chromatograph (GC) and set it up for hexane analysis and when possible, went on site to monitor hexane losses while processing conditions were being altered. It was found that in cases where the meal was heavily toasted, it was possible to significantly cut back on steam input before any increases in hexane losses were observed. However, research by the authors suggests that moisture input during desolventization be eliminated to produce a non-toasted meal, but it was found that this was not possible with the current desolventizer/toasters being used. Most desolventizer/toasters are of the Schumacher design which relies on direct steam injection to force vapours through the system in a counter current manner. Therefore, if a non-toasted meal is to be produced the systems would have to be modified and so the meals produced commercially are still toasted. In a latter section of this report, methods of producing the non-toasted meals will be discussed, but in the current meal survey the best that could be obtained was a high quality toasted meal.

Increasing Quality of Standard Toasted Meal.

The surveys of canola meal quality conducted in this research program, allowed the crushing companies an opportunity to produce a more consistent quality meal and initially this appeared to be occurring. However, part way through this study, the price of vegetable oils dropped and the crushing margins declined. As a result, most crushing plants decreased there crush levels in an attempt to minimize losses. At this time it was noted that meal quality declined again and that it was difficult to produce high quality meals when the level of production was reduced. Those plants that did not reduce crushing levels did not experience the same decline in meal quality. It appears from this finding that the quality of canola meal is somewhat dependent on how close the plant is running to capacity.

To understand the decline in meal quality with production level one has to understand the basic design of the desolventizer toaster in canola crushing plants. The desolventizer/toaster is basically a vertical tube with several trays located within it. The hexane laden meal enters the top of the cylinder and sits on the first hot tray, the meal is mixed and eventually falls to the next tray and so on. The depth of the meal on the tray is controlled by a chute. If the meal level is too low, the chute is not activated to open and let meal fall to the next tray until enough is added such that a certain depth is obtained. Therefore, the residence time in the unit is dependant on the rate of product entering the system. This works well if the machine operates at a constant rate, but when production levels are reduced significantly, the amount of time the meal spends in the unit increases. In addition, the amount of heating surface remains constant, but if the feed rate is reduced, the amount of hexane that must be evaporated is reduced and therefore too much energy is applied to the meal. In the face of fluctuating production rates it is difficult to control the level of toasting applied to the meal.

CONCLUSIONS AND RECOMMENDATIONS

Canola meal is a reasonably consistent product now but quality can suffer when production rates are reduced. It is recommended that systems be run at or near design capacity or that variable speed valves be installed such that the residence time in the unit can be directly controlled. Crushing plants should have the capacity to measure hexane levels in meals so heat input can be minimized without compromising hexane recovery.

Table 1. Apparent ileal digestibility (%) of the essential amino acids and cysteine in canola meal samples collected from canola crushing plants in Western Canada.

			Crushing Plant (average value of all meals collected from the plant)						
Amino Acid	Ave 2000	Ave 2001	1	2	3	4	5	6	7
CP	75.3	73.5	74.9	73.8	74.3	72.2	75.7	71.7	74.1
ala	82.4	80.1	82.1	81.8	81.4	79.3	82.1	77.7	79.6
arg	88.8	87.2	88.9	87.9	88.4	87.3	88.4	84.9	88.1
asp	78.1	75.8	79.3	75.5	78.0	74.7	78.3	72.3	77.1
cys	77.7	75.8	78.8	75.9	77.7	74.8	77.2	73.5	76.5
glu	88.9	87.8	89.3	88.4	88.7	87.3	89.0	85.8	88.6
gly	79.4	76.7	79.6	77.7	78.6	76.1	78.6	73.6	78.4
his	83.1	81.4	84.0	82.8	83.3	81.1	83.3	79.2	78.1
ile	81.3	78.4	80.3	80.3	79.8	77.8	80.0	76.1	80.1
leu	84.7	82.2	84.2	84.2	83.6	81.6	83.8	79.6	83.8
lys	81.3	79.0	81.8	78.7	80.7	78.2	81.5	76.4	80.2
met	88.6	86.4	88.4	87.9	87.7	85.8	87.3	84.2	88.0
phe	80.6	81.0	82.5	82.5	82.1	80.0	82.3	77.7	78.3
pro	75.2	70.4	74.8	73.4	74.4	71.4	70.8	66.4	71.7
ser	76.1	74.9	76.5	75.5	75.8	72.9	76.6	72.6	76.7
thr	72.9	69.1	70.1	70.7	69.6	68.2	70.7	67.7	71.4
val	79.7	76.8	78.2	78.1	77.8	76.1	78.7	74.6	78.8

Table 2. Essential and cysteine amino acid (g/16 g N) and crude protein (%) composition in canola meal samples collected in December 2000 from canola crushing plants located in Western Canada.

Amino Acid	Ave 2000	Ave 2001	1	2	3	4	5	6	7
CP	36.89	38.97	37.38	38.21	37.89	38.03	41.01	37.38	36.87
ala	4.20	4.19	4.20	4.20	4.14	4.20	4.17	4.20	4.20
arg	5.86	6.10	6.19	6.03	6.05	6.07	6.11	6.19	5.96
asp	6.95	7.14	7.26	6.99	7.12	7.20	7.03	7.26	7.04
cys	2.30	2.48	2.51	2.45	2.45	2.43	2.50	2.51	2.42
glu	16.62	18.04	17.77	18.35	17.37	17.53	17.79	17.77	17.45
gly	4.81	4.85	4.88	4.87	4.80	4.84	4.78	4.88	4.82
his	2.72	2.96	2.93	2.91	2.88	2.90	2.95	2.93	2.86
ile	3.80	3.91	3.94	3.87	3.85	3.89	3.84	3.94	3.87
leu	6.70	6.99	6.95	6.95	6.85	6.91	6.92	6.95	6.88
lys	5.25	5.26	5.40	5.19	5.21	5.35	5.38	5.40	5.31
met	1.89	2.00	1.96	1.99	1.93	1.95	2.00	1.96	1.98
phe	3.88	4.04	4.06	4.02	3.98	3.99	3.94	4.06	3.98
pro	6.39	6.11	6.18	6.33	6.02	6.10	6.06	6.18	6.37
ser	4.15	4.13	4.10	4.14	4.10	4.15	4.15	4.10	4.17
thr	4.15	4.20	4.16	4.20	4.10	4.23	4.18	4.16	4.23
val	4.91	5.01	5.10	5.02	4.98	4.99	4.89	5.10	4.97

REFERENCES

Kadim, I. T. and P. J. Moughan. 1997. Ileal amino acid digestibility assay for the growing meat chicken - effect of the imposition of a fasting period and the nature of the test diet. British Poultry Science 38:285-290.

NRC, 1994. Nutrient Requirements of Poultry, 9th edition. National Academy Press, Washington D.C., USA.

THE EFFECTS OF TOASTING CANOLA MEAL ON BODY WEIGHT, FEED CONVERSION EFFICIENCY AND MORTALITY IN BROILER CHICKENS

ABSTRACT

During the desolventization of solvent extracted canola, the meal is toasted and turns a brown colour. It is hypothesised that the moisture incorporated into the meal as sparge steam during desolventization causes the toasting and therefore suspending the use of sparge steam may result in a non-toasted meal. Elimination of toasting of canola meal (CM) would result in higher and more uniform digestible amino acid content but it is not known if such processing is required to reduce anti-nutritional factors in the meal. Therefore, the objectives of this study were to determine if suspending the use of sparge steam during desolventization will prevent browning and to study the effects of CM toasting on broiler chicken performance. Conventional toasted meal (TCM) and a hexane laden, non-toasted meal (NTCM) were collected from a commercial crushing plant on the same day. NTCM was desolventized in a research desolventizer/toaster without the use of sparge steam. The resulting meal contained low residual hexane and was yellow in colour. The meals were fed to 3240 broiler chickens in a 2*2*6 factorial (2 sexes* 2 types of meal* 6 levels) design replicated three times with 45 birds per floor pen from 0-39 d. TCM and NTCM replaced 0, 20, 40, 60, 80 and 100% of the soybean meal (SBM) in wheat based diets. Elimination of toasting increased broiler weight from 0.606 and 2.148 to 0.618 and 2.181 kg at 19 and 39 d of age, respectively. It also improved gain to feed ratio (0-19 d) from 0.637 to 0.642 but did not affect mortality. Replacement of up to 80% and 60% of the dietary SBM up to 19 and 39d, respectively did not affect growth rate in comparison to the control but higher levels did. Total mortality and chronic heart failure (CHF) between 19 and 39 d increased with level of CM addition from 5.2% to 13.9% and 1.9% to 9.6%, respectively. CHF in males, but not females was increased from 3.3 to 17.4% with increasing CM level. In conclusion, desolventization without sparge steam produced a non-toasted meal and improved broiler growth and feed efficiency in comparison to TCM. Therefore, NTCM can be fed to broiler chickens.

INTRODUCTION

CM has an excellent balance of amino acids, but has lower amino digestibility than soybean meal (Zuprizal et al., 1992). Previous work has shown that the desolventization/toasting stage of pre-press solvent extraction of canola reduces both the content and digestibility of amino acids and in particular lysine (Newkirk and Classen, 1999; Newkirk et al., 2000). Desolventization is the process of removing the hexane used to extract the oil in a desolventizer/toaster (DT). It is called a DT because it not only desolventizes the meal but it also imparts a toasting process to reduce the level of heat labile anti-nutritional factors in the meal.

The Schumacher DT (Crown Iron Works Company, Minneapolis, MN, USA, 55440-1364) is the most prevalent design in North America and consists of a series heated trays stacked vertically. The solvent laden meal is conveyed onto the top tray and falls from tray to tray until exiting to a drier/cooler with low residual hexane levels remaining. The first trays are internally heated with steam thereby heating the meal indirectly and causing the majority of the solvent to evaporate. The final trays apply direct heat in the form of

sparge steam injected directly into the meal. This steam condenses and increases the moisture content of the meal exiting the DT to approximately 14.5 to 18.5%.

Entering the DT, the solvent extracted CM is a yellow colour but exiting it is a brown colour indicating the Maillard reaction is occurring in the process (Newkirk and Classen, 1999). The extent of the Maillard reaction is seen by the lower lysine content and digestibility in toasted meal (Newkirk and Classen, 1999).

The optimal conditions for the Maillard reaction have been defined previously in other proteinaceous products as being between 15-18% moisture in combination with elevated temperatures (Mauron, 1981). Since sparge steam is increasing the moisture content it may contribute to the losses in amino acid content and digestibility during desolventization. Therefore the elimination of additional moisture in the form of sparge steam during desolventization/toasting may result in a yellow coloured meal with an elevated concentration of amino acids and enhanced digestibility. However, it is not known if the toasting process imparted by the sparge steam is necessary to reduce heat labile anti-nutritional factors in the meal and therefore required to optimize the nutritional value of the meal.

Therefore the objectives of the current experiment were to determine to if elimination of sparge steam during desolventization would reduce the level of browning and toasting of the meal; and to determine if the toasting process imparted by the sparge steam is required to reduce anti-nutritional factors and therefore optimize broiler performance.

MATERIALS AND METHODS

Meal Collection and Desolventization

Conventional desolventized/toasted (TCM) and non-desolventized canola meal samples were collected on the same day from a commercial canola crushing plant located in Western Canada. The oil extracted, solvent laden meal (Marc) was collected in 160 l steel drums with sealed lids and transported to POS (POS Pilot Plant Corp., 118 Veterinary Road, Saskatoon, SK, Canada, S7N 2R4) for desolventization. The Marc was desolventized in a DT (77.5 cm inside diameter) built by Crown Iron Works equipped with 2 steam heated trays (53.3 cm between trays). The line for feeding sparge steam into the meal was disconnected such that the meal was desolventized solely by indirect heat in the form of steam heated trays. The rate of flow through the unit was adjusted such that the exit temperature of the meal was approximately 100°C and no residual hexane could be detected by smell. Samples of meal exiting the DT were analysed for residual hexane according to the method of the American Oil Chemists Society (1997), erucic acid according to the method of the American Oil Chemists Society (1991, 1992) and glucosinolates according to the method of Daun et al. (1989).

Broiler Study

Day old, Peterson*Hubbard broiler chickens (3240) were randomly assigned to one of six rooms (2 sexes, 3 rooms per sex) with 12 dietary treatments per room and 45 birds per replicate (pen) on straw litter. Feed and water was provided *ad libitum* for the duration of the trial. The initial room temperature was 35°C and declined in a step wise fashion to 22°C by day 35 where it was maintained to the end of the trial. The lighting program consisted of 24L:0D, 18L:6D, 8L:8.5D:1L8.5D, 10L:6.5D:1L:6.5D, 14L:4.5D:1L:4.5D,

and 18L:6D for the periods of 0-4, 5-7, 8-14, 15-21, 22-28 and 29-29 d of age, respectively. Light intensity was 20 lux for o to 4 d of age and 5 lux thereafter.

Toasted (TCM) and non-toasted canola meal (NTCM) replaced 0, 20, 40, 60, 80 and 100% of dietary soybean meal (SBM). Diets were formulated to be isocaloric and to meet bird requirements according to the recommendations of Leeson and Summers (1997). All diets were formulated to have at least the same level of digestible Lys, Met+Cys, and Arg as the control treatment using the digestibility as reported by NRC (1994) for wheat and soybean meal and Newkirk et al. (2000) for CM. Prior to formulation, total amino acid content of feed ingredients was analysed by the performic acid method (Llames and Fontane, 1994) using a Beckman 7300 High performance Amino Acid Analyzer (Beckman Instruments, Inc., Fullerton, CA, USA 92834-3100). Neutral detergent insoluble nitrogen (NDIN) content of the NTCM and TCM was determined using an Ankom 200 Fiber Analyzer (Ankom Technology Coporation, 140 Turk Hill Park, Fairport, NY, 14450). The procedure supplied by the manufacture was used except sodium sulfite was not added to the NDF solution. Tables 1 and 2 show the composition of the starter and grower diets used in this study. Starter diets were allocated on the basis of 1.1 kg per starting chick (~ 23 d) and then pens were switched to the grower ration until the end of the experiment. Body weight (on a pen basis) was determined at 0, 19 and 39 d and feed consumption was measured throughout the trial. Serum samples were collected from four and two birds per pen at 19 and 39 d of age, respectively, for the determination of total triiodothyronine (T_3) and thyroxine (T_4) levels using a DPC Coat a Count® kit (Diagnostic Products Corporation, 5700 West 96th Street, Los Angeles, CA, USA, 90045-5597). At 39 d of age two birds per pen were individually weighed and sacrificed by cervical dislocation and weights of the heart, liver, bursa, pancreas, proventriculus, gizzard, duodenum, jejunum, ileum and cecum determined. The animal care protocol used in this experiment was approved by the University of Saskatchewan animal care committee. All experiments were conducted according to the guidelines of the Canadian Council on Animal Care (1993).

STATISTICAL ANALYSIS

The data was analysed as 2*2*6 (2 sexes*2 meal types* 6 inclusion levels) factorial with sex nested within room (12 dietary treatments within each of 3 rooms of males and 3 rooms of females) using the GLM procedure of the SAS program (SAS Institute 1989). Differences were considered significant when $P<0.05$. Means separation was conducted using the method of Duncan (1955) when significant main effects were observed. When a significant effect of dietary level was found, regression analysis was conducted using the REG procedure of the SAS program (SAS Institute 1989).

RESULTS

The solvent laden white flake was desolventized, without sparge steam, at a rate of 128 kg per hour producing 87 kg per hour of meal with a residual hexane content of 256 µg/g exiting the DT. Hexane analysis was not conducted on the conventional TCM as it was collected after the drier cooler and therefore would not be representative of meal exiting the DT directly. NTCM and TCM had similar levels of protein, lysine, methionine, cysteine and erucic acid (Table 3). The NDIN content of the TCM was 1.7

times higher than the NTCM. The NTCM contained approximately twice the level of glucosinolates as the TCM with the largest difference being the level of 4-OH-3-methylindoyl glucosinolate (Table 3). Prior to desolventization, the meal had a bitter smell that was no longer apparent once the meal had been heated to 100°C. The TCM did not have this smell. Desolventization in the absence of sparge steam did not change the colour of the meal and therefore was a light yellow colour. In contrast, the meal desolventized in the conventional manner with sparge steam was a light brown colour.

Feeding NTCM resulted in higher body weight at 19 and 39 d than TCM (Table 4). Replacement level had a quadratic effect on 19 d body weight where 20 to 60% resulted in the highest 19 d body weights but 100% the lowest. Replacing 80 or 100% of dietary soybean meal with CM also reduced 39 d body weight. Males had higher body weights at 19 and 39 d. There was an interaction between level and sex on 19 d body weight. Increasing the level of replacement from 60 to 80% resulted in a significant reduction in 19 d body weight in females but in males a depression was not observed until the level was increased from 80 to 100% (Table 5). There was also a significant interaction between meal type, soybean meal replacement level and sex on 19 d body weight. The heaviest female 19 d body weights were achieved at 40 and 60 % replacement with NTCM and TCM (Table 6), respectively. However, maximum 19 d male body weight was achieved at 60 and 40% replacement with NTCM and TCM, respectively.

Birds fed the NTCM consumed more feed between 0-19 d than those fed TCM but toasting had no effect on feed consumption between 19-39 d (Table 4). Replacement level affected feed consumption between 0-19 d but not 20-39 d. Replacing 40% of the soybean meal resulted in the highest feed consumption between 0-19 d but complete replacement of soybean meal resulted in the lowest. Males consumed more feed between 0-19 and 20-39 d than females. There was a significant interaction between meal type and replacement level on 0-19 d feed consumption. Replacement of dietary soybean meal with NTCM had a quadratic affect on feed consumption with 40% resulting in the highest intake and 100% the lowest (Table 7). Replacement with TCM resulted in a linear reduction in 0-19 d feed consumption (Table 7). There was a significant interaction of meal type, level and sex on 19-39 d feed consumption (Table 6), but the cause of the interaction is not clear.

Feeding NTCM resulted in a higher gain to feed ratio between 0-19 d than TCM (Table 4). Males had a higher gain to feed ratio between 0-39 d than females. There was a significant interaction of meal type and soybean meal replacement level on gain to feed ratio between 0-19 d. Increasing the level of TCM but not NTCM had a quadratic effect on gain to feed ratio between 0-19 d (Table 7). There was an interaction between soybean meal replacement level and sex on gain to feed ratio where males responded in a quadratic manner to inclusion level but there was no effect on females (Table 5).

There was no effect of treatment on mortality up to 19 d. TCM and NTCM resulted in similar levels of mortality and chronic heart failure (Table 4). Mortality increased with the level of CM inclusion between 19 and 39 d. The increased mortality was primarily due to chronic heart failure. Males had a higher level of mortality and chronic heart failure between 20-39 d. There was an interaction between meal type and sex on chronic heart failure. Males fed NTCM tended to have a higher level of chronic heart failure than those fed TCM (Table 8). However, females fed TCM tended to have a higher level of

chronic heart failure than those fed NTCM. There was an interaction between soybean meal replacement level and sex on mortality and chronic heart failure between 19 and 39 d. Chronic heart failure in males increased with replacement of soybean meal by CM but the same effect was not observed with females (Table 5). The same affect was observed for mortality but the data is not shown since the primary effect on mortality is reflected by the chronic heart failure values. There was an interaction between meal type, replacement level and sex on mortality between 19 and 39 d. Mortality in females was increased linearly with increasing NTCM, but not TCM level (Table 6). Mortality in males was increased linearly with increasing inclusion of both types of meals, but TCM resulted in the highest level of mortality with complete replacement of soybean meal.

Meal type or level had no effect on the organ weights other than liver, full jejunal or empty cecal weights at 39 d of age (Table 9). Conventional TCM increased liver weight, and full jejunal weight level at 39 d of age. Empty cecal weight as a percentage of body weight at 39 d was reduced linearly with replacement of soybean by CM. Females had higher proportional of liver weights than the males at 39 d. There was a significant interaction between meal type and replacement level on 39 d heart weight where replacement of soybean meal with TCM but not NTCM resulted in a linear increase in heart weight at 39 d (Table 7).

TCM resulted in higher serum T_3 at 39 d of age than NTCM. Serum T_3 at 39 d was increased by replacement level. Males had higher serum T_3 levels than females at 19 d but not 39 d (Table 10). There was a significant interaction between meal type and soybean replacement level on serum T_3 at 19 d where there was no effect of level when NTCM was fed, but it increased with TCM inclusion level (Table 7).

Males had lower serum T_4 levels at 19 d and 39 d (Table 10). There was a significant effect of soybean meal replacement level on serum T_4 level at 19 d but there was no apparent consistent relationship between the two. There was a significant interaction of level and sex on serum T_4 at 19 and 39 d. There was a quadratic effect of replacement level on serum T_4 in females at 19 d, but no effect in males at the same age (Table 5). At 39 d males fed the soybean control had the highest level of serum T_4 but 20% replacement with CM yielded the lowest. There was no apparent effect of inclusion level on T_4 in females at 39 d.

DISCUSSION

Within the crushing industry, it is a commonly held belief that direct heating through sparge steam injection is required to produce a meal with low residual hexane levels in a conventional DT. As a result, when the desolventization process was planned for this research, it was assumed that three times as much residence time in the desolventizer would be required to effectively desolventize the meal. Typically, this DT desolventizes at a rate of 100 to 150 kg per hour with sparge steam which is very similar to the rate achieved in this experiment (128 kg/hour) without sparge steam, therefore elimination of the sparge steam appeared to have little to no impact on the rate of desolventization.

The meal contained an acceptably low level of residual hexane even though sparge steam was not utilized. The residual hexane levels in the meal were higher than that normally achieved in this unit (~100 ppm) but would still appear to fall within acceptable limits. The level of residual hexane in the meal exiting the DT in commercial plants is

not regulated directly but overall solvent losses in the process are. The United States Environmental Protection Agency has recently enacted a new rule (40 CFR Part 63) which limits the loss of hexane during processing to 2.65 l/tonne of canola seed processed for existing plants and 1.136 l/tonne for new plants. Losses of hexane in the meal and the drier/cooler exhaust air are believed to account for 70-80% of the losses of hexane in a commercial solvent extraction plant (Myers, 1983). Therefore, assuming 80% of the loss is due to residual hexane in meal exiting the DT, and the seed is 60% oil, the maximum allowable hexane in the residual hexane exiting the DT is 2332 ppm for existing plants and 999 ppm for new plants. The level of hexane in the final meal would have to be, and is, considerably lower however as hexane is lost from the meal during the drying cooling process after exiting the DT. Residual hexane levels in finished soybean meal have been reported to range from 100 to 3000 µg/g with average values being approximately 500 µg/g (Myers, 1983). The rate of desolventization and residual hexane content was not determined with sparge steam in this experiment so our results can only be compared to those normally obtained in this plant. It is premature to recommend elimination of sparge steam during desolventization in a commercial process; however, the current data suggest that it might be possible.

One of the hypotheses of this research was that the elimination of sparge steam during desolventization should reduce or eliminate browning due to a reduction in moisture content during desolventization. If water, in the form of condensed sparge steam, is not added to the meal during desolventization, browning should be prevented because moisture is required to promote Maillard reactions (Lea and Hannan, 1949) to proceed at an appreciable rate. Desolventization with out sparge steam did result in a light yellow coloured product and did not appear to brown the product to any extent which supports this hypothesis. The NDIN content of the NTCM, which has been shown to be positively correlated with protein damage during desolventization processing (Newkirk et al., 2000) was lower than the NTCM which also indicates the elimination of sparge steam prevented damage during desolventization.

The meal prior to desolventization had a bitter smell that was no longer detectible once the meal had been heated to 100 C. This volatile bitter compound(s) might be the degradation product of glucosinolates such as thiocyanate, 5-vinyl oxazolididinr-2-thione, 1 cyanyo-2-hydroxy-3 butene, isothiocyanate or nitriles (Subuh et al., 1995) produced during the crushing process but prior to desolventization. Previous research found that heating CM to 100°C with or without steam improved feed intake and growth in broiler chicks (Shires et al., 1983). Part of the improvement in growth with heating was related to the denaturation of myrosinase activity in the meal but it may be possible this volatile compound(s) is also a factor. Effective commercial desolventization, with or without sparge steam, requires heating the meal to ensure the residual hexane content is minimized. In the current experiment, effective desolventization did not occur until the meal reached approximately 100°C so it is unlikely that this bitter compound will become an issue if canola crushers reduce the use of sparge steam during desolventization.

The NTCM contained approximately twice the level of glucosinolates as the TCM, which also indicates the degree of toasting was reduced. Glucosinolates are heat labile and reduction during desolventization/toasting is well known (Jensen et al., 1995) but it appears that sparge steam also enhances the rate of their degradation.

The NTCM in the current experiment contained less 3-butenyl, 4-pentenyl, 2-OH-3-butenyl and 2-OH-4-pentenyl glucosinolates than reported for a conventional TCM from 1988 (Table 3) and a survey of meals published in 1991 (Bell and Keith, 1991), indicating plant breeding has further reduced the aliphatic glucosinolates since that time. The TCM contained similar levels of 4-OH-3-methylindoyl glucosinolates as the 1988 conventional meal, indicating genetic selection has not reduced this compound. The 4-OH-3-methylindoyl (Neoglucobrassicin) was most affected by the conventional toasting process, which is consistent with the findings of Jensen et al. (1995) but the toxic effects of glucosinolates are generally thought to be attributed to the aliphatic not the indolyl glucosinolates (Darroch and Bell, 1991). Therefore, it is unlikely that the reduction in glucosinolates in this case would have any major impact on toxicity of the meal. Conventional toasting reduced Neoglucobrassicin by 82% and total glucosinolates by 55%, however it did not improve bird performance. The birds fed the non-toasted meal were significantly heavier at 19 and 39 D, indicating the level of glucosinolates prior to toasting were not impairing performance.

Complete replacement of soybean meal with CM in the starter, and 80% replacement in the finisher did impair body weight as compared to the wheat soybean meal control. However, it does not appear that the effect is due to glucosinolates as the non-toasted meals out performed the toasted meals even at the highest levels of inclusion. Serum thyroid hormones, T_3 and T_4, were not reduced by the CM as would be expected if the glucosinolates were impairing thyroid function (Bell et al., 1991), further suggesting the depression at high inclusion levels is not due to the glucosinolate concentration. The current findings are in agreement with that of Swierczewska et al. (1995) who demonstrated that feeding low glucosinolate varieties as whole seed (0.9 µmol/g seed) to broiler chickens had no effect on serum T_3 levels. Previous studies have also demonstrated shown similar reductions in body weight of broiler chickens with high levels of CM inclusion (Kocher et al., 2000) but the cause was not known. However, replacement of more than 60% of the soybean meal in diets is impractical due to the low nutrient density of CM.

The toasted meal resulted in lower body weights at 19 and 39 d than the non-toasted meal possibly due to a reduction in nutritional value as a result of toasting (Newkirk et al., 2000). The increase in NDIN content supports this hypothesis but the fact that lysine content was similar between the two meals does not. The improvement in gain to feed ratio with 20, 60 and 80% soybean meal replacement by NTCM but not conventional meal also suggests the nutritional composition of the non-toasted meal may have been greater than that of the toasted. Replacement of up to 60% of the soybean meal with either the TCM or the NTCM resulted in final body weights as high as the control, indicating that both TCM and NTCM can be used to replace a portion of the soybean in the diet with no adverse affects on performance. Toasting did degrade some of the glucosinolates in the meal and the breakdown products may have had a toxic effect, reducing bird growth rate and feed intake (Subuh et al., 1995).

Birds fed conventional toasted meal, had larger livers than those fed non-toasted meal, which may indicate the toasting process is producing toxic compounds that have to be detoxified in the liver. Toasting also increased the full jejunal weight but the cause is not known, but may related to a reduced rate of digestion and therefore more materials

remaining in this section of the gut. The reduction in empty cecal weight with CM is likely due to decreased fermentation in the cecum as soybean meal contains more indigestible but fermentable sugars such as stachyose and raffinose than CM (Leske and Coon, 1999). Another possibility is that CM may have some anti-microbial compounds capable of reducing cecal fermentation.

CM inclusion increased mortality levels. A previous study also showed that feeding high levels of CM increased mortality levels (Classen et al., 1991). The primary cause was due to leg abnormalities, in contrast to chronic heart failure in this experiment. Mortality was increased by both toasted and non-toasted meals indicating the cause was not thermal breakdown products of glucosinolates or due to heat labile toxic factors that are removed by the DT. The effect of replacing soybean meal with CM on chronic heart failure was more evident and consistent in males, which are more prone to chronic heart failure. This is generally thought to be to due to the faster rate of gain and higher rate of metabolism in males (Olkowski and Classen, 1998). The earliest varieties of rapeseed were associated with heart disease, which was attributed to the high level of erucic acid in the oil (Abdellatif, 1979). However, the level of erucic acid in the present study was low so it is unlikely to have contributed to the incidence of heart failure. Chronic heart failure (ascites) has also been associated with increased metabolic rate in broiler chickens as measured by increased serum T_3 levels (Scheele et al., 1992). The increase in chronic heart failure with higher T_3 levels is thought to be as a result of the increase in metabolic rate caused by the elevated serum T_3, which increases the demand for oxygen and places additional demands on the heart. Therefore, the increased chronic heart failure with CM inclusion may be related to the elevation of serum T_3 levels. The reason the broilers in this study were more prone to chronic heart failure than in previous studies is not known. However, increased growth rate of modern broilers and environmental factors may have interacted with feeding CM to predispose birds to chronic heart failure. The reason T_3 levels increased with canola meal inclusion is not known, but it appears this is the first published report of this occurring.

Feeding TCM did result in a linear increase in heart weight as a proportion of the body weight, which may be a sign of chronic heart failure due to an increased rate of metabolism. However, feeding the NTCM did not impact heart weight in the same manner.

CM is thought to have a bitter flavour which may reduce feed intake due to the presence of sinapine (Clandinin, 1961). Between 0-19 d the highest level of CM inclusion did reduce feed intake, which would support this hypothesis. However, there was no effect on feed intake between 20-39 d suggesting CM is palatable to older birds. Toasting appears to reduce palatability as feed intake was reduced in comparison to NTCM (0-19). It is not known why toasting would reduce feed intake but numerous flavoured compounds are produced as a result of mallard reactions. However, the products of toasting are normally associated with enhanced flavour (Mauron, 1981), however. Toasting does cause glucosinolate degradation and the resulting products may be reducing feed intake in young birds. Toasting did not appear to affect palatability in older birds, as feed intake was not affected.

The increase in gain to feed ratio in males (0-19 d) with 20% replacement of soybean meal may be due to an underestimation of the metabolisable energy content of the canola

oil used in the diet. However, gain to feed ratio of the males did not continue to increase with CM inclusion nor was there any effect in females at the same age. Overall (0-39 d) there was no effect of inclusion level on gain to feed ratio indicating the diets were likely iso-energenic and iso-nitrogenous.

CONCLUSIONS AND IMPLICATIONS

In conclusion, desolventization without sparge steam results in a light coloured meal and appears to reduce if not eliminate toasting. Desolventization with out sparge steam also resulted in the highest body weights which suggest that there are no anti-nutritional factors in CM that need to be reduced by the toasting process. If the use of sparge steam can be suspended the cost of producing the steam will be avoided and the potential to destroy essential amino acids almost eliminated. However prior to a general recommendation to eliminate CM toasting, the impact of this process must be studied on other species such as swine or cattle. CM can be used to replace a portion of soybean meal in broiler diets, but complete replacement of soybean meal by CM impairs performance. High levels of CM in the diet also increased metabolic rate and the incidence of chronic heart failure in males but the cause is not known.

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REFERENCES

Abdellatif, A. M. M. 1979. The factor in rapeseed oil and the factor in the rat Pathologic changes in the heart due to high erucic acid content. Voeding. 40: 385-388.

American Oil Chemists Society, 1991. Determination of fatty acids in edible oils and fats by capillary GLC. Official Method Ce 1e-91. American Oil Chemists Society, Champaign, IL.

American Oil Chemists Society, 1992. Preparation of methyl esters of long-chain fatty acids. Official Method Ce 2-66. American Oil Chemists Society, Champaign, IL.

American Oil Chemists Society, 1997. Total hexane content in extracted meals. Official Method Ba 14-87. American Oil Chemists Society, Champaign, IL.

Bell, J. M., and M.O. Keith, 1991. A survey of variation in the chemical composition of commercial canola meal produced in western Canadian crushing plants. Can. J. Anim. Sci. 71: 469-480.

Bell, J. M., M.O. Keith, and D.S. Hutcheson, 1991. Nutritional evaluation of very low glucosinolate canola meal. Can. J. Anim. Sci. 71: 497-506.

Canadian Council on Animal Care, 1993. Guide to the care and use of experimental animals. 2nd edition. E.D. Olfert, B.M. Cross, A.A. McWilliam, eds. CCAC, Ottawa, ON.

Clandinin, D. R., 1961. 4. Effect of sinapin, the bitter substance in rapeseed oil meal, on the growth of chickens. Poultry Sci. 40: 484-487.

Classen, H. L., J.M Bell, and W.D. Clark, 1991. Nutritional value of very low glucosinolate canola meal for broiler chickens. Proceedings of the GCIRC Eighth International Rapeseed Congress. 2: 390-395.
Darroch, C. S. and J.M. Bell, 1991. Potential goitrogenic and toxic effects of an indolyle glucosinolate extract injected into the developing chick embryo. Can. J. Anim. Sci. 71: 481-487.

Daun, J.K., D.R. DeClercg, and D.I. McGregor, 1989. Analysis of glucosinolates in canola and rapeseed. Method of the Canadian Grain Commission. Grain Research Laboratory, Canadian Grain Commission, Winnipeg, MB.

Duncan, D. B., 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Jensen, S. K., Y.G. Liu, and B.O. Eggum, 1995. The effect of heat treatment on glucosinolates and nutritional value of rapeseed meal in rats. Anim. Feed Sci. Technol. 53: 17-28.

Kocher, A., M. Choct, M.D. Porter, and J. Broz, 2000. The effects of enzyme addition to broiler diets containing high concentrations of canola or sunflower meal. Poultry Sci. 79: 1767-1774.

Lea, C. H. and R.S Hannan, 1949. Studies of the reaction between proteins and reducing sugars in the "dry" state, I. The effect of activity of water, of pH and of temperature on the primary reaction between casein and glucose. Biochemica et Biophysica Acta 3: 313-325.

Leeson, S., and J.D. Summers, 1997. Commercial Poultry Nutrition, 2nd edition. University Books, Guelph, ON, Canada.

Leske, K. L., and C.N. Coon, 1999. Hydrogen gas production of broiler chicks in response to soybean meal and alpha-galactoside free, ethanol-extracted soybean meal. Poultry Sci. 78: 1313-1316.

Llames, C. R. and J. Fontane, 1994. Determination of amino acids in feeds: Collaborative study. J. AOAC Internat. 77: 1362-1402.

Mauron, J., 1981. The Maillard reaction in food; a critical review from the nutritional standpoint. Prog. Food Nutr. Sci. 5: 5-35.

Myers, N. W., 1983. Solvent recovery. JAOCS 60:224-225.

Newkirk, R. W., and H.L. Classen, 1999. The effects of standard oilseed extraction and processing on the nutritional value of canola meal for broiler chickens. Poultry Sci. [Suppl. 1] 78: 39.

Newkirk, R. W, H.L. Classen, T.A. Scott, and M.J. Edney, 2000. Commercial desolventization-toasting conditions reduce the content and digestibility of amino acids in canola meal. Poultry Sci. [Suppl. 1] 79: 64.

NRC, 1994. Nutrient Requirements of Poultry, 9th edition. National Academy Press, Washington D.C., USA.

Olkowski, A. A. and H.L. Classen, 1998. High incidence of cardiac arrhythmias in broiler chickens. J. Vet. Med. 45: 83-91.

SAS Institute, 1989. *SAS/STAT User's Guide*. Cary, NC: SAS Institute Inc.

Scheele, C. W., E. Decuypere, P.F.G. Vereijken, and F.J.G. Schreurs, 1992. Ascites in broilers. 2. Disturbances in the hormonal regulation of metabolic rate and fat metabolism. Poultry Sci. 71: 1971-1984.

Shires, A., J.M. Bell, J.A. Blake, P. Fedec, and D.I. Mcgregor, 1983. The feeding value of canola meal for broiler chickens as affected by heat and steam during desolventization and by fibre reduction. 1983. Seventh Project Report. Canola Council of Canada. Research on Canola Seed, Oil, Meal and Meal Fractions. pp 12-16.

Slominski, B. A., and L.D. Campbell, 1990. Non-starch polysaccharides of canola meal: Quantification, digestibility in poultry and potential benefit of dietary enzyme supplementation. J. Sci. Food Agric. 53: 175-184.

Subuh, A. M. H., T.G. Rowan, and T.L.J. Lawrence, 1995. Toxic moieties in ruminal and duodenal digesta and in milk, and hepatic integrity in cattle given diets based on rapeseed meals of different glucosinolate contents either untreated or treated with heat or formaldehyde. Anim. Feed Sci. Technol. 52: 51-61.

Swierczewska, E., B. Reklewska, and A. Siennicka, 1995. Serum thyroxine and triiodothyronine concentrations in growing and adult meat type birds fed "00" rapeseed-containing diet during the first seven weeks of life. J. Anim. Feed Sci. 4: 35-42.

Zuprizal, M. Larbier, and A.M. Chagneau, 1992. Effect of age and sex on true digestibility of amino acids of rapeseed and soybean meals in growing broilers. Poultry Sci. 71: 1486-1492.

Table 1. Starter diet composition and calculated nutrient composition

Treatment	1,7	2,8	3,9	4,10	5,11	6,12
Replacement Level	0	20	40	60	80	100
Ingredients %						
Wheat	73.52	70.98	67.93	63.24	58.55	53.85
Soybean meal	20.84	16.64	12.79	8.32	4.16	
Canola meal[1]	0.00	6.27	12.48	20.83	28.87	36.91
Canola oil	1.0	1.63	2.33	3.3	4.28	5.25
Dicalcium Phosphate	1.45	1.42	1.39	1.34	1.30	1.25
Limestone	1.74	1.68	1.61	1.52	1.44	1.35
Sodium Chloride	0.37	0.38	0.38	0.39	0.40	0.40
Vit/Min premix [2]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Chloride	0.10	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.10	0.09	0.07	0.05	0.03	0.01
L-Lysine HCL	0.18	0.20	0.21	0.20	0.18	0.17
Avizyme 1302[3]	0.05	0.05	0.05	0.05	0.05	0.05
Coxistac[4]	0.10	0.10	0.10	0.10	0.10	0.10
Stayfac 22[5]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Nutrient Composition (%)						
AME_n (kcal/kg)	2926	2925	2925	2925	2925	2925
Crude protein	20.20	20.20	20.25	20.59	20.92	21.25
Calcium	1.00	1.00	1.00	1.00	1.00	1.00
Non Phytate Phosphorus	0.42	0.42	0.42	0.42	0.42	0.42
Lys	1.06	1.07	1.08	1.09	1.10	1.12
Available Lys	0.95	0.95	0.95	0.95	0.95	0.95
Met + Cys	0.83	0.84	0.86	0.88	0.91	0.93
Available Met + Cys	0.68	0.68	0.69	0.71	0.72	0.73

[1]Non-toasted canola meal used in treatments 1-6, conventional toasted canola meal used in treatments 7-12.
[2]Supplied per kilogram of diet: 11000 IU vitamin A (retinyl acetate + retinyl palmitate), 2200 IU vitamin D_3, 30 IU vitamin E (dl-α-tocopheryl acetate), 2.0 mg menadione, 1.5 mg thiamine, 6.0 mg riboflavin, 60 mg niacin, 4 mg pyridoxine, 0.02 mg vitamin B_{12}, 10.0 mg pantothenic acid, 6.0 mg folic acid, 0.15 mg biotin, 0.625 mg ethoxyquin, 500 mg calcium carbonate, 80 mg Fe, 80 mg Zn, 80 mg Mn 10 mg Cu, 0.8 mg I, and 0.3 mg Se.
[3]Finnfeeds International Ltd., Marlborough, Wiltshire, UK, SN8 1AA.
[4]Pfizer Canada, London, ON, Canada, N6A 1K7contains Salinomycin sodium 60 g/kg.
[5]SmithKline Beecham, Mississauga, ON, Canada, L5N 6L4, contains Virginiamycin 22g/kg.

Table 2. Grower diet composition and calculated nutrient composition

Treatment	1,7	2,8	3,9	4,10	5,11	6,12
Soybean replacement %	0	20	40	60	80	100
Ingredients %						
Wheat	77.12	74.71	72.31	69.91	67.51	64.61
Soybean meal	15.02	12.01	9.01	6.01	3.01	0
Canola meal[1]		4.81	9.60	14.39	19.18	24.40
Canola oil	2.00	2.00	2.00	2.00	2.00	2.00
Tallow	1.41	2.09	2.77	3.46	4.14	4.92
Dicalcium Phosphate	1.39	1.37	1.34	1.32	1.30	1.27
Limestone	1.60	1.55	1.50	1.45	1.39	1.34
Sodium Chloride	0.37	0.37	0.38	0.38	0.39	0.39
Vit/Min premix[2]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Chloride	0.10	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.10	0.08	0.07	0.06	0.05	0.04
L-Lysine HCL	0.20	0.21	0.21	0.22	0.23	0.23
Avizyme 1302[3]	0.05	0.05	0.05	0.05	0.05	0.05
Coxistac[4]	0.10	0.10	0.10	0.10	0.10	0.10
Stayfac 22[5]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Nutrient Content (%)						
AME (kcal/kg)	3100	3100	3100	3100	3100	3100
Crude protein	18.05	18.08	18.11	18.14	18.18	18.28
Calcium	0.92	0.92	0.92	0.92	0.92	0.92
Non-phytate phosphorus	0.40	0.40	0.40	0.40	0.40	0.40
Potassium	0.65	0.64	0.63	0.62	0.61	0.61
Sodium	0.18	0.18	0.18	0.18	0.18	0.18
Lysine	0.91	0.92	0.92	0.93	0.94	0.94
Available Lys	0.81	0.81	0.81	0.81	0.81	0.81
Met + Cys	0.77	0.78	0.78	0.79	0.80	0.82
Available Met + Cys	0.62	0.62	0.62	0.63	0.64	0.64

[1]Non-toasted canola meal used in treatments 1-6, conventional toasted canola meal was used in treatments 7-12.
[2]Supplied per kilogram of diet: 11000 IU vitamin A (retinyl acetate + retinyl palmitate), 2200 IU vitamin D_3, 30 IU vitamin E (dl-α-tocopheryl acetate), 2.0 mg menadione, 1.5 mg thiamine, 6.0 mg riboflavin, 60 mg niacin, 4 mg pyridoxine, 0.02 mg vitamin B_{12}, 10.0 mg pantothenic acid, 6.0 mg folic acid, 0.15 mg biotin, 0.625 mg ethoxyquin, 500 mg calcium carbonate, 80 mg Fe, 80 mg Zn, 80 mg Mn 10 mg Cu, 0.8 mg I, and 0.3 mg Se.
[3]Finnfeeds International Ltd., Marlborough, Wiltshire, UK, SN8 1AA.
[4]Pfizer Canada, contains Salinomycin sodium 60 g/kg .
[5]Smith Kline Beecham, contains Virginiamycin 22g/kg.

Table 3. Chemical composition (% of dry matter) of toasted (TCM), non-toasted canola meal (NTCM), Tobin TCM from 1988 and a very low glucosinolate variety of TCM from 1988

	NTCM	TCM	1988 Tobin Meal[1]	1988 Very Low Glucosinolate meal[1]
Crude protein	42.51	41.13	39.73	39.66
Lysine	2.25	2.25	2.19	2.23
Methionine	0.84	0.88	0.83	0.79
NDIN (% of protein)	11.31	19.73	ND	ND
Erucic acid (% of meal)	0.003	0.008	ND	ND
Erucic acid (% of oil)	0.130	0.190	ND	ND
Glucosinolates (umoles/g)				
Allyl	0.15	0.27	0.00	0.00
3-butenyl	3.21	1.94	4.21	0.00
4-pentenyl	0.55	0.34	2.12	0.00
2-OH-3-butenyl	5.81	3.88	7.78	0.00
2-OH-4-pentenyl	0.12	0.04	0.87	0.00
methylthiobutenyl	0.14	0.12	ND	ND
methylthiopentenyl	0.09	0.16	ND	ND
4-OH-benzyl	0.73	0.78	0.00	0.00
3-methylindoyl	0.72	0.31	0.17	0.04
4-OH-3-methylindoyl	10.37	1.88	2.21	0.49
Total glucosinolates	21.89	9.72	17.36	0.58

[1]Adopted from Bell et al. 1995.
ND, Not determined.

Table 4. Body weight, average feed consumption, gain to feed ratio, mortality and chronic heart failure (CHF) level in broiler chickens fed toasted (TCM) and non-toasted canola meal (NTCM)

	Average body weight		Average feed consumption		Gain to feed		Mortality 19-39 d	
	19 d	39 d	0-19 d	19-39 d	0-19 d	19-39 d	Total	CHF
	(kg)		(kg/bird)		(kg/kg)		(%)	
NTCM	0.618[a]	2.181[a]	0.905[a]	3.193	0.642*a*	0.545	9.6	5.2
TCM	0.606[b]	2.148[b]	0.891[b]	3.140	0.637*b*	0.546	8.9	5.5
Level of Replacement								
0	0.614[ab]	2.184[a]	0.905[a]	3.140	0.635	0.543	5.2[d]	1.9[b]
20	0.623[a]	2.207[a]	0.911[a]	3.179	0.643	0.550	7.8[bcd]	3.7[b]
40	0.621[a]	2.184[a]	0.913[a]	3.150	0.640	0.544	6.9[cd]	3.3[b]
60	0.623[a]	2.200[a]	0.909[a]	3.190	0.645	0.551	10.2[abc]	6.7[a]
80	0.609[b]	2.137[b]	0.893[a]	3.157	0.642	0.546	11.7[ab]	6.9[a]
100	0.582[c]	2.072[c]	0.856[b]	3.176	0.634	0.542	13.9[a]	9.6[a]
Regression	Quadratic	Linear	Quadratic	NS	NS	NS	Linear	Linear
Male	0.629[a]	2.270[a]	0.919[a]	3.373[a]	0.646	0.554[a]	13.7[a]	8.4
Female	0.594[b]	2.058[b]	0.877[b]	2.957[b]	0.634	0.538[b]	4.8[b]	2.3
SEM	0.003	0.015	0.005	0.030	0.004	0.005	0.88	0.68
	Probability							
Type	***	**	**	0.09	*	NS	NS	NS
Level	***	***	***	NS	NS	NS	***	***
Sex	***	***	***	***	***	***	***	***
Type *level	NS	NS	*	NS	**	NS	NS	NS
Type*sex	NS	NS	NS	NS	NS	NS	NS	*
Level*sex	*	0.09	NS	NS	*	NS	**	**
Type*level*sex	*	NS	NS	*	NS	NS	**	NS

a,b,c,d Means within a column and main effect without a common superscript differ significantly (P<0.05).

*,**,*** Significant at P<0.05, P<0.01, and P<0.001 respectively; NS, non-significant (P>0.05).

Table 5. The interaction between level of replacement of soybean meal with canola meal and sex on 19 d body weight gain to feed ratio (0-19 d), chronic heart failure (20-39 d) and serum T_4 (19 and 39 d) in broiler chickens

	Body weight (19 d)		Gain:Feed (0-19 d)		Chronic heart failure (19-39 d)		Serum T_4 (19 d)		Serum T_4 (39 d)	
Replacement	Males	females	males	females	males	females	males	females	males	females
	(Kg)		(Kg/Kg)		(%)		(ηg/dl)			
0	0.630[a]	0.597[ab]	0.642[b]	0.628	3.3[c]	0.4[b]	389	756	750[a]	768
20	0.645[a]	0.601[ab]	0.654[a]	0.632	5.6[bc]	1.9[b]	445	603	428[b]	853
40	0.640[a]	0.602[a]	0.647[ab]	0.632	5.2[c]	1.5[b]	466	589	671[ab]	673
60	0.642[a]	0.603[a]	0.648[ab]	0.643	11.1[b]	2.2[b]	557	618	693[ab]	718
80	0.629[a]	0.589[b]	0.649[ab]	0.634	7.8[bc]	5.9[a]	361	623	509[ab]	757
100	0.589[b]	0.574[c]	0.633[c]	0.636	17.4[a]	1.9[b]	507	824	566[ab]	813
Regression	Quadratic	Quadratic	Quadratic	NS	NS	NS	NS	Quadratic	NS	NS

a,b,c Means within a column without a common superscript differ significantly ($P<0.05$).
NS, non-significant ($P>0.05$).

Table 6. The interaction between sex, level of soybean meal replacement and toasting of canola meal on body weight (0-19d), feed consumption (19-39 d), mortality (20-39d) and serum T_3 levels (19 d)

		Body weight (0-19 d)		Feed Consumption (19-39 d)		Mortality (19-39 d)		Serum T_3 (19 d)	
Sex	Level	NTCM	TCM	NTCM	TCM	NTCM	TCM	NTCM	TCM
		(kg)				(%)		(ng/dl)	
Female	0	0.597	0.597	0.892	0.892	2.6	2.6	228	228
	20	0.608	0.594	0.896	0.885	2.2	6.7	210	228
	40	0.611	0.593	0.908	0.872	2.2	1.5	257	228
	60	0.602	0.605	0.886	0.882	3.0	8.2	197	289
	80	0.594	0.585	0.863	0.869	11.1	8.2	219	257
	100	0.589	0.561	0.852	0.829	6.7	3.0	238	239
Regression		Quadratic	Quadratic	NS	Quadratic	Linear	NS	NS	NS
Male	0	0.630	0.630	0.919	0.919	7.8	7.8	250	250
	20	0.657	0.634	0.952	0.910	14.1	8.2	254	245
	40	0.637	0.643	0.947	0.926	15.6	8.2	265	238
	60	0.661	0.623	0.966	0.904	17.8	11.9	266	245
	80	0.638	0.621	0.908	0.930	11.1	16.3	265	283
	100	0.600	0.577	0.884	0.860	18.5	27.4	255	275
Regression		Quadratic	Quadratic	NS	NS	Linear	Linear	NS	Linear

NS, non-significant (P>0.05).

Table 7. The interaction between soybean meal replacement and toasted (TCM) and non-toasted canola meal (NTCM) on feed consumption and gain to feed from 0-19 d , serum T_3 levels at 19 d and proportional heart weight (% of body weight) at 39 d of broiler chickens

	Feed consumption (0-19d)		Gain:feed (0-19d)		Serum T_3 (19 d)		Heart weight (39 D)	
Replacement	NTCM	TCM	NTCM	TCM	NTCM	TCM	NTCM	TCM
	(kg)		(kg/kg)		(ηg/dl)		(% body weight)	
0	0.905^{ab}	0.905^{a}	0.635^{b}	0.635^{abc}	239	239^{b}	0.46^{ab}	0.46^{b}
20	0.924^{a}	0.897^{a}	0.645^{a}	0.641^{ab}	232	237^{b}	0.48^{a}	0.43^{b}
40	0.927^{a}	0.899^{a}	0.634^{b}	0.646^{a}	261	233^{b}	0.43^{b}	0.50^{a}
60	0.926^{a}	0.893^{a}	0.645^{a}	$0.645ab$	231	$267a$	0.50^{a}	0.47^{ab}
80	0.886^{bc}	0.900^{a}	$0.650a$	0.633^{bc}	242	270^{a}	0.46^{ab}	0.50^{a}
100	0.868^{c}	0.845^{b}	0.642^{ab}	0.627^{c}	246	257^{ab}	0.48^{a}	0.50^{a}
Regression	Quadratic	Linear	NS	Quadratic	NS	Linear	NS	Linear

a,b,c Means within a column without a superscript differ significantly (P<0.05).
NS, non-significant (P>0.05).

Table 8. The interaction between sex and meal type (toasted, TCM, and non-toasted canola meal (NTCM) on the incidence of chronic heart failure and serum T_3 in broiler chickens between 19-39d

	Chronic heart failure (%)[z]	
Canola meal type	Males	Females
NTCM	9.8	2.4
TCM	9.0	3.0
	Serum T_3 (ng/dl)[z]	
Canola meal type	Males	Females
NTCM	235[b]	241
TCM	271[a]	257

[z]Excludes data from treatments 1 and 7 since they did not contain either type of canola meal.
a,b Means within a column without a common superscript differ significantly ($P<0.05$).

TABLE 9. The effect of feeding toasted (TCM) and non-toasted canola meal (NTCM) on liver, jejunal (full) and ileal weight (empty) and serum thyroid hormone levels at 39 d of age

	Organ weight			
	Liver	Full jejunal	Empty cecal	Heart
	(% body weight)			
NTCM	2.79[b]	2.14[b]	0.29	0.48
TCM	2.92[a]	2.30[a]	0.28	0.47
Level of Replacement				
0	2.78	1.98	0.37[a]	0.46
20	2.82	2.20	0.31[b]	0.46
40	2.76	2.22	0.29[bc]	0.46
60	2.94	2.32	0.27[c]	0.48
80	2.08	2.29	0.27[c]	0.48
100	2.94	2.16	0.26[c]	0.49
Regression	NS	NS	Linear	NS
Male	2.77[b]	2.08	0.28	0.48
Female	2.92[a]	2.35	0.29	0.47
SEM	0.030	0.037	0.006	0.005
	Probability			
Type	*	*	NS	NS
Level	NS	NS	*	NS
Sex	*	***	NS	NS
Type *level	NS	NS	NS	***
Type*sex	NS	*	NS	NS
Level*sex	NS	NS	NS	NS
Type*level*sex	NS	*	NS	NS

a,b,c,d Means within a column and main effect without a common superscript differ significantly (P<0.05).

*,**,*** Significant at P<0.05, P<0.01, and P<0.001 respectively; NS, non-significant (P>0.05).

TABLE 10. The effect of feeding toasted (TCM) and non-toasted canola meal (NTCM) on serum thyroid hormone levels at 19 and 39 d of age

	19 d		39 d	
	T_3	T_4	T_3	T_4
	(ηg/dl)			
Non-toasted	241	558	235[b]	711
Conventional	253	565	263[a]	653
Level of Replacement				
0	239	565[ab]	224[d]	759
20	234	524[b]	230[cd]	683
40	247	529[b]	236[bcd]	673
60	249	589[ab]	256[abc]	706
80	256	495[b]	262[ab]	633
100	252	669[a]	267[a]	695
Regression	NS	NS	Linear	NS
Male	258[a]	458[b]	250	601[b]
Female	235[b]	661[a]	246	763[a]
SEM	4.0	21.4	4.59	24.4
	Probability			
Type	NS	NS	**	NS
Level	NS	*	*	NS
Sex	***	***	NS	***
Type *level	*	NS	NS	NS
Type*sex	*	NS	NS	NS
Level*sex	NS	*	NS	*
Type*level*sex	*	NS	NS	NS

a,b,c,d Means within a column and main effect without a superscript letter differ significantly (P<0.05).

*,**,*** Significant at P<0.05, P<0.01, and P<0.001 respectively; NS, non-significant (P>0.05).

IDENTIFICATION AND ISOLATION OF BITTER COMPOUNDS IN CANOLA MEAL PRIOR TO DESOLVENTIZATION AND TOASTING

INTRODUCTION

During the production of non-toasted meal for the study examining the effect of toasting on broiler performance, it was noticed that the solvent laden meal had a very astringent smell prior to desolventization. Although one would expect the product to have a solvent smell, hexane does not have a bitter odour so the smell had to be due to some other component in the meal or solvent. When the meal was desolventized at POS, the system initially was not assembled correctly and some meal was dumped out of the system prematurely. Most of the hexane had evaporated but the meal only hit a temperature of ~90°C. The meal produced in this manner had the very astringent smell, but once the system was fixed and the meal was heated to 100°C the bitter smell was no longer present. The identity of this compound is not known nor is it known if it would affect performance of animals if found in the feed. Shires et al., 1983 found that if canola was not heated to 100°C that feed intake and performance of broiler chicks suffered, it was concluded that the cause of the poor performance was likely due to residual myrosinase activity in the meal, but it might be possible that this bitter compound could have been a factor. In this report, several methods of producing non-toasted meal is presented and some of those options would result in the meal never achieving 100°C so this compound might become an issue. Therefore, the objectives of this study were to identify the compounds responsible for the astringent smell, to locate the source of the compounds, to isolate the compounds and to test the effects of the compound(s) on broiler performance.

MATERIALS AND METHODS

Identification of Astringent Compounds

Since meal desolventized at low temperature had this astringent odour but those heated to 100°C did not it was assumed the responsible compounds had a boiling point between 90 and 100°C and would therefore be good candidates for separation and analysis by gas liquid chromatography.. Since the compounds were still present in the meal after hexane extraction, it was assumed that the compounds would have some degree of polarity and might therefore be retained to a certain degree on a polar mobile phase such as the StabilWax® DA column by Restek.

A 25 g sample of air desolventized canola meal was placed in 50 ml glass septum vial and sealed with a rubber septa and aluminium cap. The vial was heated in an oven to 110°C for 30 minutes prior to collecting a 100 ul sample of gas from the vial with a gas tight, glass syringe. The head space gas was then injected into a Varian Model 3400 Gas Chromatograph, equipped with a Restek Stabilwax®-DA 30 M long, 0.25 mm Id capillary column. Hydrogen was used as a carrier gas at 2.7 ml/min (100 cm/sec velocity). The column oven was set to 105°C, the injector was set at 220°C with a 1:10 split ratio. The compounds were then detected with a flame ionization detector.

The identity of the main compound found in the head space gas sample as described above was determined using a GC-Mass spec located at the Prairie Biotechnology Institute – National Research Council, Saskatoon, SK. The molecular weight of the compound of interest was determined as well as the fragmentation pattern determined. By comparing the molecular weight and fragmentation pattern with those in a library of samples, the potential identity of the compound was determined

Isolation of the Astringent Compounds for a Feeding Study

Based on the identity of the primary astringent compound in canola meal, it was hypothesised that the hexane pool used to extract canola meal may contain large quantities of the compounds of interest. A sample (20L) of hexane was collected from the water/solvent separator at a commercial crushing plant. The hexane was then distilled using a Soxlet extractor by heating until the hexane had evaporated and the temperature of the solvent increased to 80°C. The resulting compounds were then collected into 50 ml glass septum vials, sealed with rubber septum and stored at room temperature until incorporated in the experimental diets.

Determination of Effects on Broiler Performance

A broiler growth study was conducted with 150 Male Ross 308 broiler chicks raised in wire floored Petersime battery cages. Six treatments (Table 1) were applied to the diets. Each treatment was replicated 5 times with 5 birds in each replicate pen. The birds were fed the experimental diets between 0-21 days and feed intake and body weight was determined weekly. The control diet was composed of 68.5% wheat, 24.7% soybean meal, 1.42% canola oil plus vitamins mineral and Avizyme 1302 xylanase. The diet was formulated to meet or exceed NRC 1994 recommendations for all nutrients. The diet contained 3010 kcal/kg AME, 23.1% CP, 0.95% Ca, 0.42% non-phytate P, 1.2% lysine, 0.90% met + cys.

Table 1. Experimental treatments in broiler study.

Treatment	Experimental treatments applied to broiler diets
1	Control (Wheat/soybean meal diet, 0 umol/g diet)
2	Control – hexane added (0.8 g/kg)
3	2.5 mmol/kg of nitrile mixture (0.2 g/kg, purified from hexane pool)
4	5 mmol/kg of nitriles (0.4g/kg)
5	7.5 mmol/kg nitriles (0.6 g/kg)
6	10 mmol/kg nitriles (0.8 g/kg)

RESULTS AND DISCUSSION

Gas liquid chromatography of the head space gas from a sample of non-toasted canola meal revealed the presence of at least 9 separate compounds. GC-Mass spectroscopy indicated that the primary compound had a molecular weight of 95.1 and based on fragmentation pattern it closely resembled 2 – pentene nitrile a synthetic compound used in the manufacture of vinyl. Considering this is a synthetically manufactured compound it seemed unlikely to find it in canola so attempts were made to find the source of the compound. Since the compound contains a nitrile group and Glucosinolates are thermally unstable it seemed reasonable that the compound may be a breakdown product of one of

the Glucosinolates. The 3 butenyl glucosionolate has an R group similar to that of 2-pentene nitrile however the double bond is in the wrong location. Since the location of the double bond would not affect the molecular weight and have little impact on the fragmentation pattern it was concluded that likely the product formed would be 4 pentene nitrile. Figure 1 shows the structure of 3 butenyl glucosinolate found in canola and the potential breakdown products 4 pentene nitrile + S + H2O. Therefore it was concluded that the primary compound found in the headspace gas from non-toasted canola was likely 4 pentene nitrile.

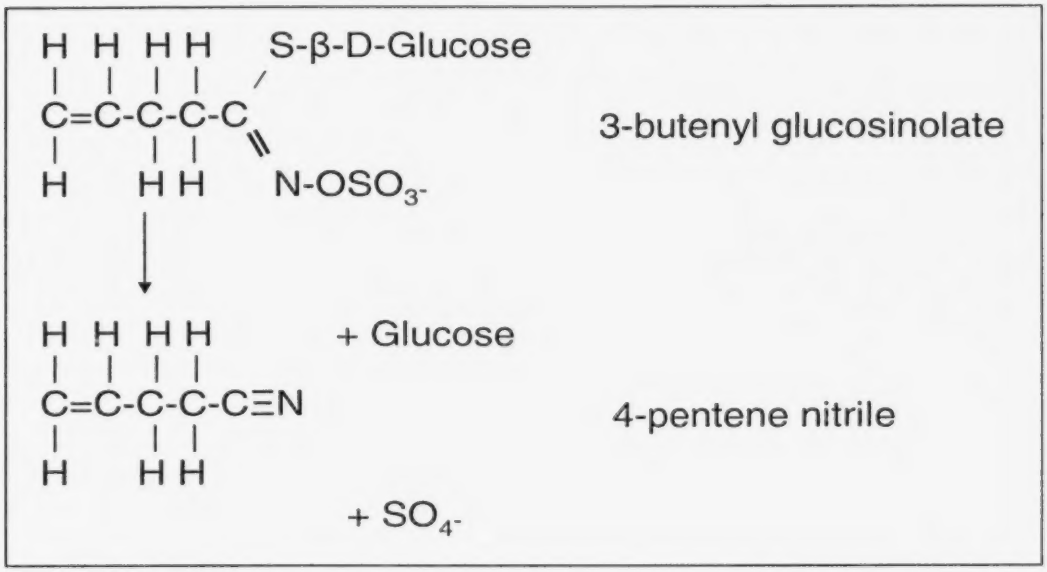

Figure 1. Proposed reaction for the formation of 4-pentene nitrile from 3 butenyl glucosinolate during canola desolvenitization.

Since this astringent compound is likely a volatile breakdown product of canola meal, one would have to ask why the levels would be so high in solvent extracted, low temperature desolventized meal since the thermal degradation should occur during toasting. It was then hypothesized that these astringent compounds, including 4-pentene nitrile are produced during toasting but that a large portion of them are being volatized during desolventization. The volatilized compounds would then be vented off to the condenser with the hexane vapours and condense with the recycled hexane. If this were the case, then the compounds would eventually build up concentration in the hexane pool used to extract the seed until equilibrium was met. Therefore to test if these compounds are concentrated in the commercial hexane pool and to produce product for animal testing, solvent was collected from a commercial crushing plant. As hypothesized, the hexane from the crushing plant had the same astringent odour that the low temperature desolventized meal had suggesting the compounds were accumulating in the solvent pool. A sample of the commercial solvent was injected into the GC and the presence of the compounds was confirmed and appeared to comprise approximately 1.5% of the solvent

on a wt/wt basis. Since it appeared that the compounds had a boiling point higher than 90°C, it was hypothesized that this compound could be recovered from the solvent by evaporating the hexane. Therefore, the solvent 20L was evaporated until the temperature hit 80°C and the remaining solution collected and analysed. After concentration, the same 9 peaks with 4 pentene nitrile being the predominant peak were visible. In addition, 32 other peaks that were apparently to low for detection prior to concentration were also visible.

Since the nitriles found in the meal had a very astringent odour it was hypothesized that they reduce the palatability of the diet. The level of nitriles in the diet was estimated to be ~ 0.5 g/kg if the nitrile in the hexane was not removed during desolventization. Therefore a broiler study was conducted with 4 graded levels of nitriles in the diet. Since, the purified nitriles may still have traces of hexanes in them a control with 0.8 g/kg of hexane was added to the diet. Unexpectedly, nitrile addition did not reduce feed intake of broiler chicks, in fact there was a trend towards increased feed intake at low levels (Figure 2). It is possible that feed intake might be negatively affected at higher inclusion levels but it is unlikely the concentration in the meal would reach levels higher than those used in this study.

Similarly, nitrile levels had no significant effect on body weight at 21 d of age. There was a trend towards increased body weight at 0.2 and 0.4 g/kg inclusion levels. This suggests that at the levels fed, the nitriles found in the commercial canola solvent pool are not toxic to birds at the levels fed in this study.

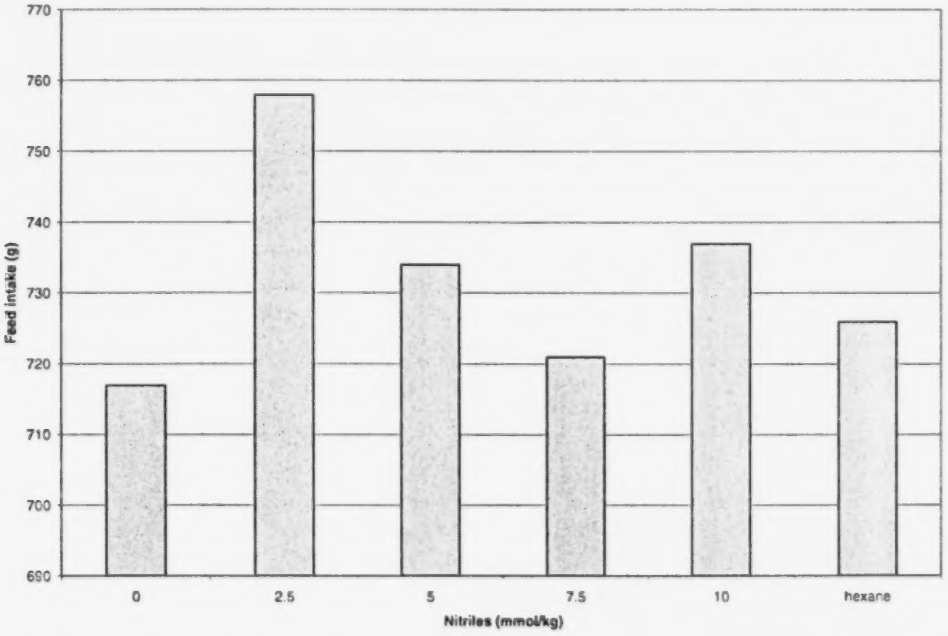

Figure 2. The effect of nitriles isolated from commercial solvent at canola crushing plant on broiler feed intake between 0-21 d of age.

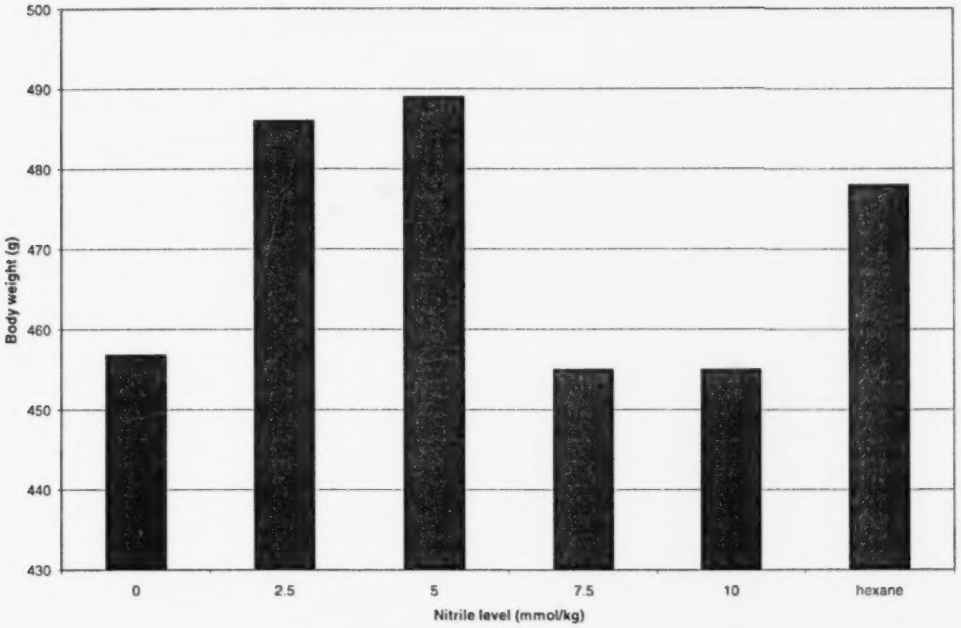

Figure 3. The effect of nitriles isolated from commercial solvent at canola crushing plant on broiler body weight at 21 d of age.

There was no significant effect of nitriles on feed to gain ratio (Figure 4), but again there was a trend towards improvements with the low inclusion levels, indicating that the nitriles were not affecting the digestive capacity of the birds.

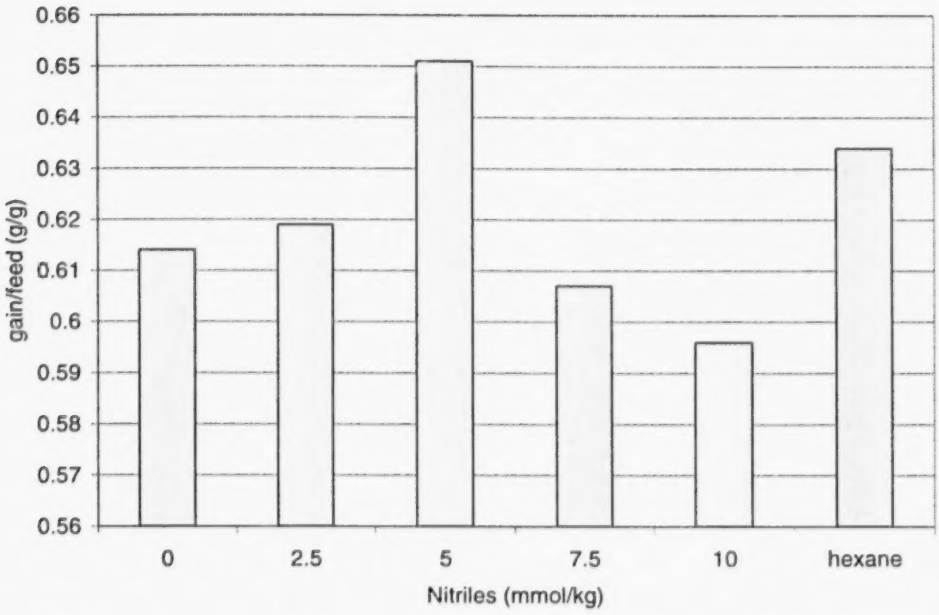

Figure 4. The effect of nitriles isolated from commercial solvent at canola crushing plant on gain to feed ratio of broiler chicks between 0 and 21 d of age.

CONCLUSIONS AND RECCOMENDATIONS

The astringent compounds found in low temperature desolventized canola meal are likely the thermal breakdown products of Glucosinolates. The compounds are volatile and the majority of them evaporate with the hexane during desolventization of the meal. The nitrile compounds then condense with the hexane and become part of the solvent pool used to extract canola meal and accounts for their presence in non-toasted meal. The primary compound appears to be the breakdown product of 3 – butenyl glucosinolate and is likely 4-pentene nitrile. The compounds found in the hexane had no negative effects on broiler performance at levels estimated to be found in canola meal if heat is not applied during desolventization. If the industry moves to the production of non-toasted canola meal, these compounds will not be produced to the same degree but since the boiling point is higher than hexane some may be found in the meal as a result of being present in the solvent pool used for extraction. Further studies should be conducted to identify all 42 compounds found in the solvent and to determine if they have any industrial or agricultural applications.

REFERENCES

Shires, A., J. M. Bell, J. A. Blake, P. Fedec, and D. Mcgregor, I. 1983. The feeding value of canola meal for broiler chickens as affected by heat and steam during desolventization and by fibre reduction. In: Seventh progress report. Research on Canola Seed, Oil, Meal and meal fractions. pp. 12-16. Canola Council of Canada, Winnipeg, Manitoba.

ASSESMENT OF PROTEIN SOLUBLITY, NEUTRAL DETERGENT INSOLUBLE NITROGEN AND NEAR INFRARED REFLECTANCE AS PREDICTORS OF THE DIGESTIBLE AMINO ACID CONTENT OF PROCESSED CANOLA MEALS.

ABSTRACT

Protein solubility in 0.5% KOH, neutral detergent insoluble nitrogen (NDIN) and near infrared reflectance spectroscopy (NIRS) was used to predict the digestibility and digestible content of amino acids in canola meal. Commercial canola meal samples (57) were analysed for amino acid content and digestibility using broiler chickens and correlated with protein solubility, NDIN and NIRS predicted values. Digestibility and digestible content of amino acids increased linearly with protein solubility in 0.5% KOH, especially lysine (R^2=0.65 and 0.74 for digestibility and digestible content, respectively). However, the fit to the line was poor in the range of 30 to 50% protein solubility, indicating this assay would only be suitable to monitor meal for excessive heat damage. There was a negative linear relationship between NDIN content and digestibility and digestible content of lysine (R^2=0.78) and all the other essential amino acids. NIRS accurately predicted lysine digestibility (R^2=0.92) as well as the digestible content of lysine (R^2=0.84) and cysteine (R^2=0.77) indicating it has the potential to be used to monitor canola meal quality. However, effective development of a NIRS calibration requires a larger validation set than is currently available and therefore NDIN is recommended until additional samples are available for calibration and validation.

INTRODUCTION

Canola meal is used as a source of protein for agricultural animals as it has an excellent balance of amino acids. However, during desolventization/toasting of the meal, both the content and availability of the amino acids can be reduced (sections 3.41 and 3.42). Currently there are only two methods available to assess if meal has been damaged during the desolventization/toasting process, amino acid content and protein solubility in 0.5% KOH.

The amino acid content of canola meal, particularly lysine content is reduced by excessive toasting (Section 3.41). The amino acid analysis procedure requires expensive HPLC equipment and dedicated technicians to conduct the analysis. As a result, Canadian canola crushing plants are not currently equipped to conduct the analysis. Since the analysis is so expensive and time consuming, only occasionally are suspect samples sent to commercial labs for amino acid analysis (personal communication, Fred Buschau, Cargill Ltd.).

Protein solubility in canola meal is reduced during heat processing as the native structure of the protein is disrupted (Pastuszewska et al., 1998). Therefore, protein solubility should provide a measure of how much heat has been applied to the meal during the desolventization/toasting process (Parsons et al., 1991) . The procedure is relatively simple, only requires basic laboratory equipment and a can be completed in a matter of hours. Although reductions in protein solubility have been demonstrated with excess heating of canola meal in a laboratory it is not known if it correlates with amino

acid content and digestibility in commercial canola meal samples (Pastuszewska et al., 1998) .

Neutral detergent insoluble nitrogen (NDIN) is that portion of the protein that is not solubilized during the analysis of neutral detergent fibre and therefore remains in the residue. The NDIN content of canola meal has been shown to increase from 7.1% to 19.1% of the crude protein during desolventization/toasting (Mustafa et al. 2000) so may indicate if meal has been overheated during processing. Due to the insoluble nature of the NDIN one might expect the digestibility of this protein to be low. Therefore, NDIN might also be an indicator of amino acid digestibility after heat processing.

Near Infrared Reflectance Spectroscopy (NIRS) is commonly used procedure to estimate the content of protein and moisture in feed ingredients. The analysis of the sample is simple and rapid requiring only a few minutes. It is based on the principle that C-H, O-H, N-H, C-C and C=O bonds absorb thermal radiation at specific wavelengths. By applying thermal radiation to the sample and measuring the amount of reflected light at specific wavelengths between 1100 and 2500 nm, one can determine the chemical composition of feed ingredients. However, it is not known if NIRS can be used to predict the digestible amino acid content in canola meal.

Therefore, the objective of this study was to determine if soluble protein in 0.5% KOH, NDIN or NIR can be used to predict the available amino acid content in processed canola meals.

MATERIALS AND METHODS

As previously described in section canola meal samples were collected from crushing located across western Canada and analysed for amino acid content and apparent digestibility in broiler chicks. The meal samples were analysed in duplicate for protein solubility in 0.5% KOH as described by (Pastuszewska et al., 1998).

NDIN content of the canola meal samples was determined in duplicate using an Ankom 200 Fiber Analyzer (Ankom Technology Coporation, 140 Turk Hill Park, Fairport, NY, 14450). Canola meal (0.5 g) ground to pass through a 0.5 mm screen was weighed in to Filter bags (Ankom Technology Corp, F57) and heat sealed. The filter bags (20), neutral detergent solution (2 l, Ankom Technology, premixed chemical solution-FND20) and 1.36 million modified Wohlgemuth Units of heat stable amalyase (Ankom Technology, FAA) were added to the analyzer and allowed to agitate for 60 minutes at 100°C. The solution was then drained from the analyzer and washed with an additional 2 l of hot (90-100°C) distilled water with agitation for 5 minutes, this wash procedure was repeated three times. The water was gently squeezed out of the filter bags by hand prior to soaking in acetone for 3 minutes. The acetone was allowed to evaporate prior to drying the bags in an oven at 105°C for 4 hours. The protein content of the residue in the filter bags were then analysed according to the methods of the Association of Official Analytical Chemists (1990) using the Kjeldahl method. NDIN was then expressed as the proportion of the protein in the meal remaining in the NDF residue.

Samples were scanned from 400 to 2500 nm at 2 nm intervals with a NIRSystems 6500 (FOSS-NIRSystems, Inc., Silver Spring, MD) using NSAS v3.53 using a standard sample cup. The calibrations were developed with WinISI v1.04. Calibrations were developed using modified PLS under WinISI, first derivative math treatment was used for

cystine, lysine and Lys/cp availability. Second derivative math treatment was used for methionine availability. The spectral region used in developing the calibration was 650 to 2500 nm. Due to limited access to the NIRS system used in this study, calibration sets were only produced for apparent lysine digestibility and apparent digestible lysine, methionine and cysteine content of canola meals.

Regression analysis of the data was conducted using the Proc RSREG and REG procedures of the SAS program (SAS Institute 1989).

RESULTS AND DISCUSSION

Protein solubility in KOH

Apparent digestibility coefficient (Table 1) increased linearly with protein solubility in (0.5% KOH). The most effective regression equations were found for lysine as might be expected since it is the most susceptible to damage during heating. However, the R^2 of the regression was only 0.65 for apparent lysine digestibility indicating it would not be a reliable predictor of available lysine content in canola meal. The reason for the low R2 value is a result of a poor fit of the regression line to the data between 20-60% protein solubility (Figure 1). As previously reported (Anderson-Hafermann et al., 1993), very low protein solubility does indicate over processing and suspect protein quality. However, several samples had a protein solubility of approximately 30% but apparent lysine digestibility in these samples ranged from 65 to 85%. Therefore, this procedure is not recommended to predict apparent lysine digestibility in normally processed meals.

Apparent digestible content of amino acids (Table 2) also increased linearly with protein solubility in (0.5% KOH) with lysine having the strongest regression line (R^2=0.74). Apparent digestible lysine content was more accurately predicted by protein solubility in KOH than lysine availability with markedly less points deviating from the regression line (Figure 2). This would indicate that protein solubility in KOH could potentially be used to estimate apparent digestible lysine content of canola meal. The apparent digestibility of the other amino acids should not be estimated using protein solubility in KOH as the R2 of the prediction lines were less than 0.70. However, since lysine is the most susceptible to damage during processing, if the meal contains high levels of digestible lysine the other amino acids should be highly available as well.

Table 1. Regression analysis of NDIN and KOH protein solubility versus amino acid digestibility coefficient in canola meal samples

Predictor	NDIN (% of CP)			Protein solubility in KOH		
Amino Acid	slope	Intercept	R^2	slope	intercept	R^2
Arg	-0.0092	1.00	0.65	0.0017	0.80	0.59
Cys	-0.017	0.98	0.69	0.0029	0.62	0.58
His	-0.0086	0.96	0.56	0.0017	0.77	0.59
Ile	-0.015	0.95	0.64	0.0025	0.63	0.48
Leu	-0.011	0.95	0.56	0.0018	0.72	0.40
Lys	-0.016	1.01	0.78	0.0028	0.67	0.65
Met	-0.017	1.04	0.47	0.0034	0.65	0.50
Phe	-0.0097	0.95	0.56	0.0017	0.75	0.45
Thr	-0.018	0.95	0.67	0.0031	0.57	0.57
Val	-0.013	0.94	0.63	0.0023	0.67	0.53

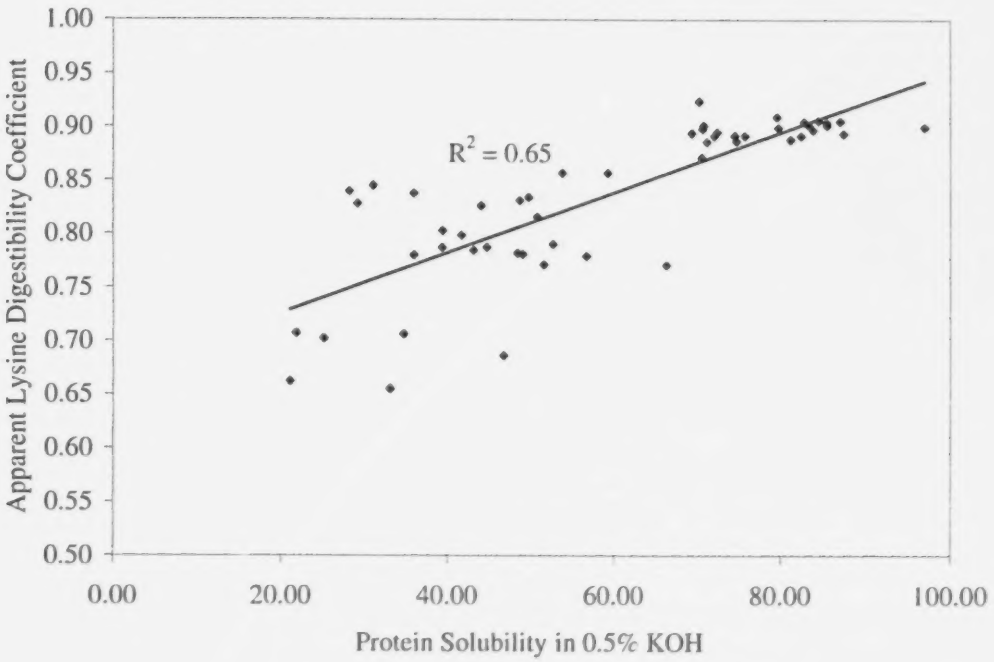

Figure 1. Protein solubility in 0.5% KOH of commercial canola meal samples versus apparent lysine digestibility in broiler chickens.

Table 2 Regression analysis of NDIN and KOH protein solubility versus digestible amino acid content (% as is) in canola meal samples

Predictor	NDIN (% of CP)			Protein solubility in KOH		
Amino Acid	Slope	Intercept	R^2	slope	intercept	R^2
Arg	-0.034	2.43	0.58	0.0064	1.67	0.56
Cys	-0.016	0.92	0.40	0.0026	0.59	0.26
His	-0.014	1.22	0.43	0.0032	0.88	0.57
Ile	-0.030	1.67	0.63	0.0053	1.022	0.54
Leu	-0.037	2.67	0.49	0.0066	1.89	0.44
Lys	-0.056	2.51	0.78	0.011	1.26	0.74
Met	-0.012	0.81	0.28	0.0023	0.54	0.25
Phe	-0.020	1.50	0.53	0.0037	1.06	0.49
Thr	-0.033	1.67	0.62	0.0063	0.93	0.60
Val	-0.03	2.08	0.58	0.006	1.36	0.57

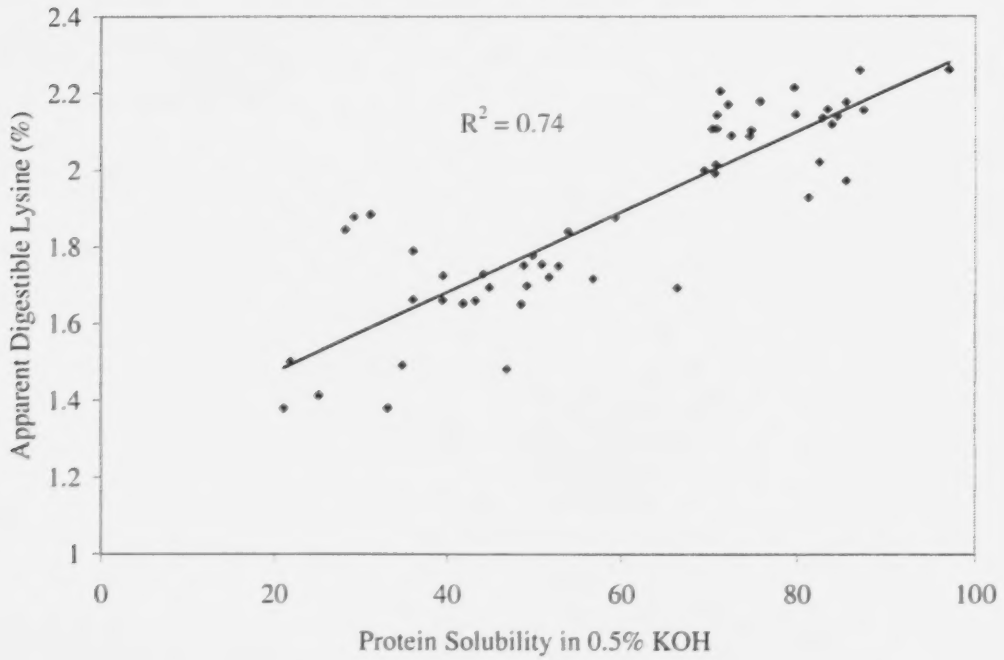

Figure 2. Protein solubility in 0.5% KOH versus apparent digestible lysine content of canola meal for broiler chickens.

Neutral Detergent Insoluble Nitrogen

NDIN was negatively correlated with the apparent digestibility of all the essential amino acids in canola meal but especially lysine (Table 1). This would suggest that the NDIN fraction is poorly utilized by broiler chickens and could be used to estimate the

apparent digestibility of lysine in canola meal. As indicated by the higher R^2 value, NDIN was a better predictor of apparent digestibility of all the amino acids tested except cysteine and histidine. NDIN was a more consistent predictor of apparent lysine digestibility than protein solubility in 0.5% KOH (Figures 1 and 2).

The apparent digestible amino acid content of all the amino acids tested was reduced linearly with increasing NDIN Content (Table 2), especially lysine. While both NDIN and protein solubility in 0.5% KOH were related to apparent digestible content of amino acids, NDIN had higher R^2 values for all the amino acids tested except histidine, suggesting NDIN is a more effective predictor.

NDIN has the advantage of being available in most feed testing laboratories. It is low cost and has a fast turnaround time so is would be practical for a feed manufacturer to have each new batch of canola meal tested. Both protein solubility and NDIN values are only a reflection of the degree of damage that has occurred during processing so the regression equations presented in Tables 1 and 2 should only be applied to canola meals and not assumed the same equations will be effective for other feed ingredients, especially unprocessed ones.

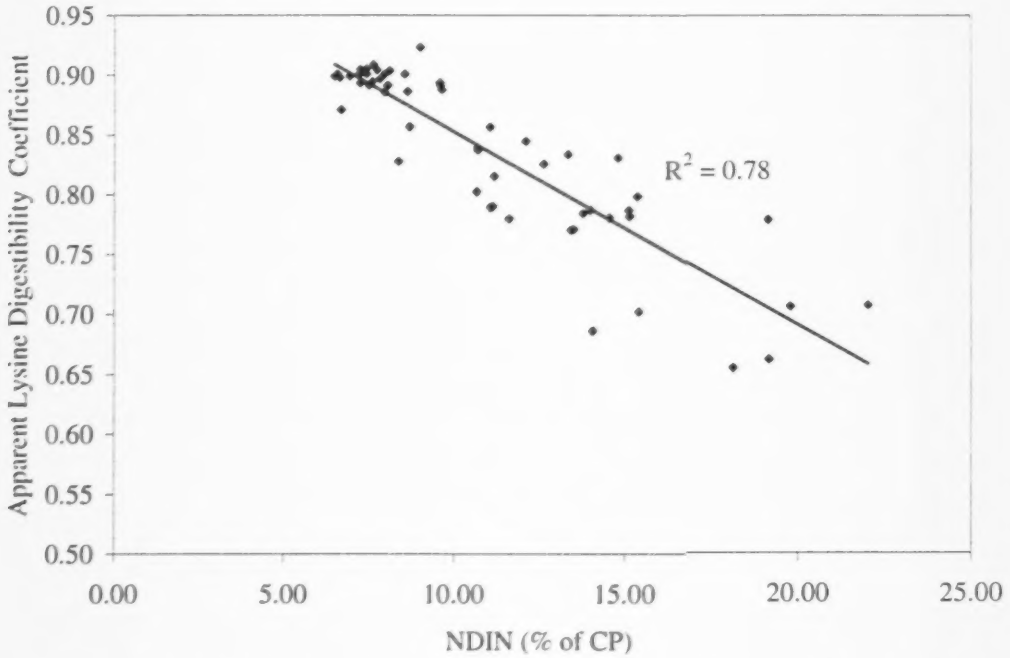

Figure 3. Neutral Insoluble Nitrogen Content (as % of CP) of canola meal samples versus lysine digestibility in broiler chickens.

Near Infrared Reflectance Spectroscopy

The scanned reflectance spectra (450 to 2500 nm) of three samples with varying amounts of digestible lysine are shown in Figure 4. The marked differences in NIR spectral scans suggest it should be possible to determine digestible lysine levels in canola meal.

The scan spectra used in the calibration of the system was limited to 1100 to 2500 nm as many of the NIRS systems available commercially do not operate below 1100 nm. Using this range of spectra effective prediction equations were produced by NIRS for both apparent lysine digestibility (Figure 5) and content (Figure 6). NIRS also predicted available cysteine content (Figure 7) but was not effective in predicting the available Methionine content (Figure 8).

This initial data suggests that NIRS has the potential to be used to predict the available content of amino acids in canola meal but effective calibration of NIRS requires a larger set of samples with known available amino acid contents than is currently available. Year to year variation in canola meal spectra would likely require the NIRS systems be recalibrated and validated at least on an annual basis. Therefore additional work is required before NIRS can be used commercially to predict amino acid digestibility and digestible content of amino acids. However, the current data suggests that NIRS may be a more accurate, cost effective and rapid than the protein solubility or NDIN assays.

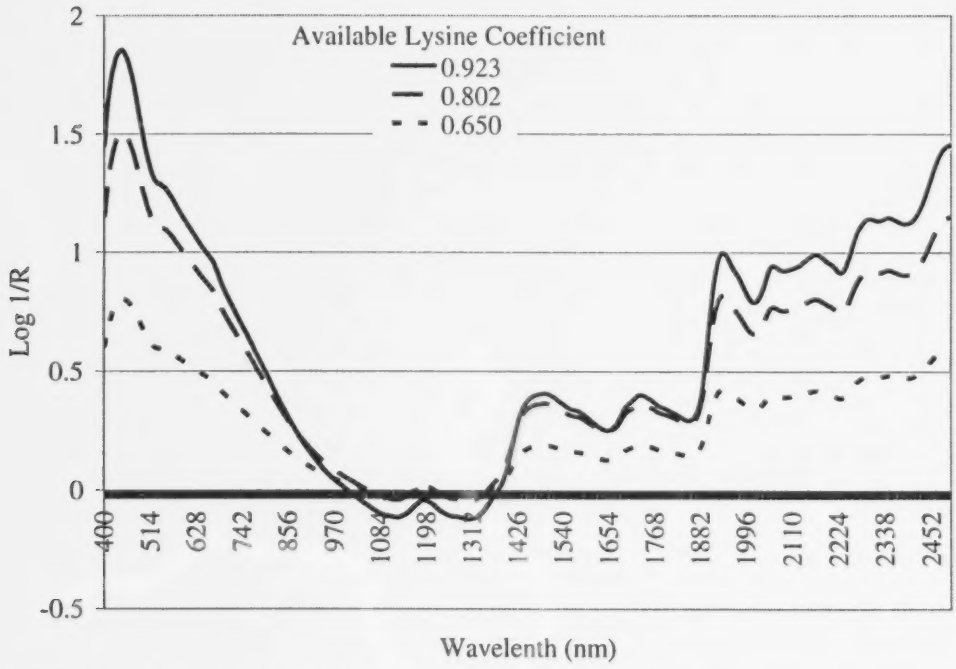

Figure 3. NIRS scan spectra of 3 canola meal samples differing in apparent lysine digestibility.

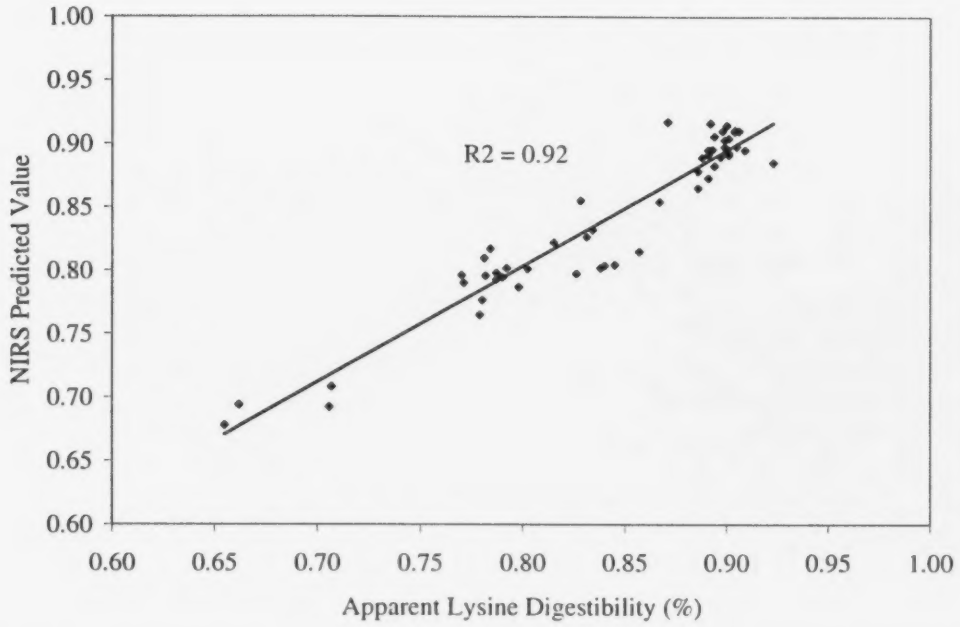

Figure 4. Apparent lysine availability in canola meal versus the NIRS predicted values.

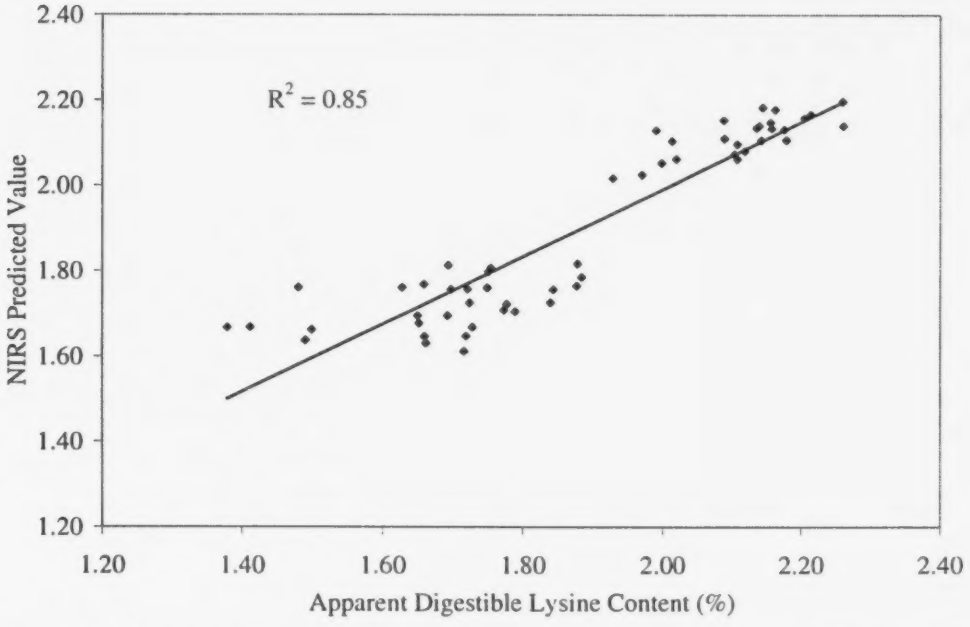

Figure 5. Apparent digestible lysine content in canola meal versus values predicted by NIRS.

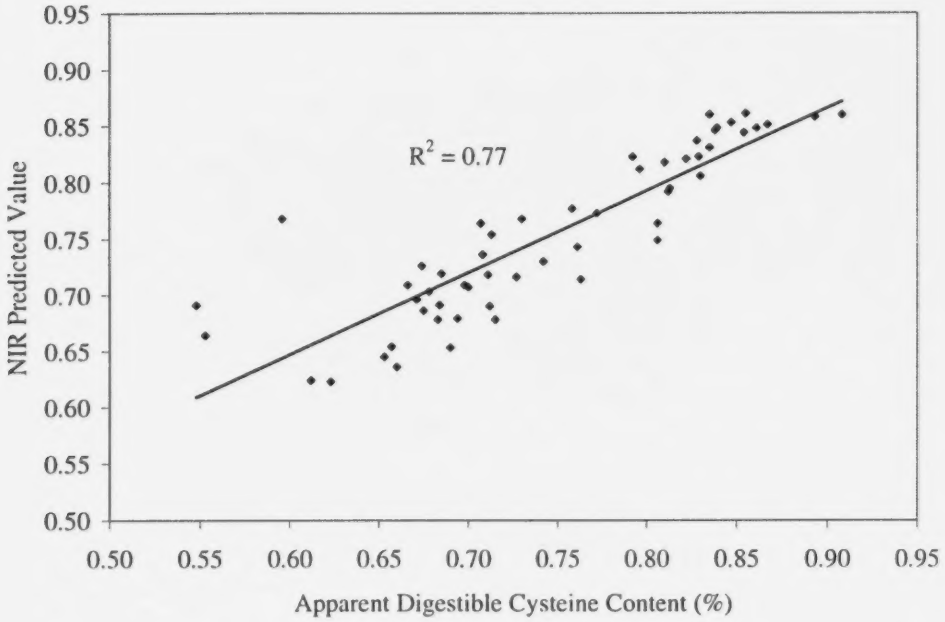

Figure 6. Apparent digestible cysteine content in canola meal versus the values predicted by NIRS.

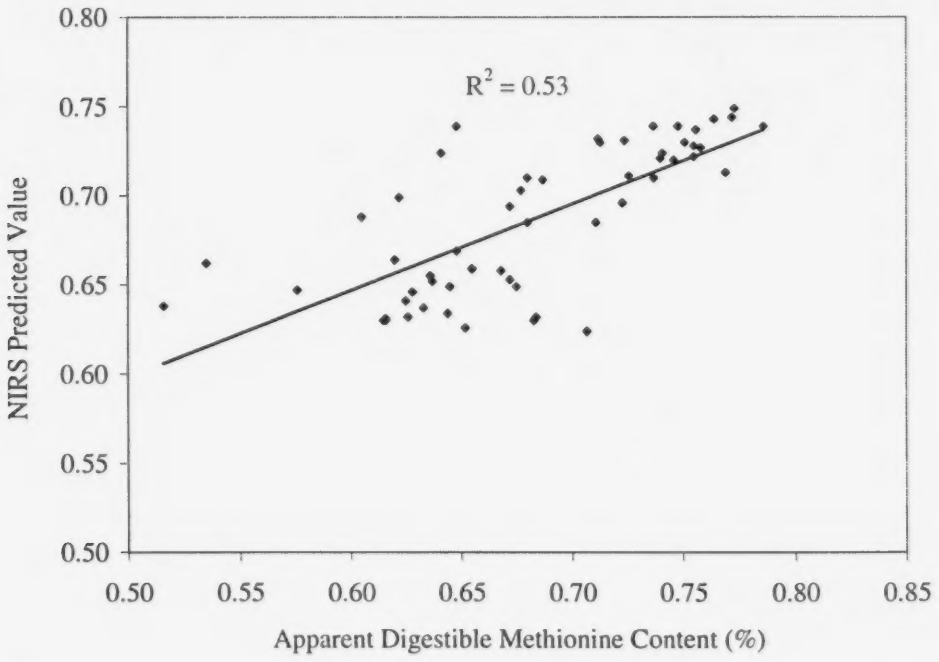

Figure 7. Apparent digestible methionine content in canola meal versus the values predicted by NIRS.

ADDITIONAL SAMPLES FOR METHOD VALIDATION

As described earlier in this report another 42 samples have been collected and analysed for amino acid content and digestibility. Degussa-Hulls agreed to conduct the amino acid analyses on the meal, diet and digesta samples in return for use of the data in a NIRS calibration set which they provide to the feed industry. It was decided that this would be the most effective way of making the data available to consumers of canola meal and the program was conducted as agreed. The full NIRS calibrations are not yet available at the time of this writing because as noted earlier in this report, that there has been an unforeseen delay in the analysis of the remaining samples for the determination of digestible amino acid content. Degussa has conducted some preliminary calibration work and reports that, using the limited data currently available, that amino acid content is predicted accurately. However, they report difficulties in estimating digestible content of canola meal with the current set of samples. It is hoped that a better calibration curve for digestible amino acid content will be developed once the remaining amino acid analyses have been conducted and the calibration set is expanded, but NIRS might have limited capacity to predict digestible amino acid content.

CONCLUSIONS

The availability and content of amino acids in canola meal can be adversely affected during processing making it necessary to monitor meal quality on a routine basis. Protein solubility in (0.5% KOH) is reduced by heating and is negatively correlated with digestible lysine content of canola meals and therefore would be effective in screening for excessively toasted meals. The NDIN fraction of the protein in canola meal is increased by heating during processing and appears to be poorly utilized by broiler chickens. NDIN as a percentage of the protein in canola meal is correlated with amino acid digestibility and apparent digestible amino acid content , especially lysine, indicating it can be used to monitor meal quality after processing. The R^2 values for NDIN were higher than protein solubility for most of the amino acids suggesting it is a better assay for monitoring meal quality. NDIN has the advantage of being low cost, fast and available in most feed testing facilities. NIRS appears to accurately predict lysine digestibility, digestible lysine and cysteine content. NIRS is the fastest and simplest of procedures but requires expensive equipment. However, effective NIRS calibration requires larger number of samples than currently available and constant validation so is not currently available to monitor meal quality. Therefore, until standard calibration sets become available for NIRS, it is recommended that NDIN be used to monitor canola meal quality.

REFERENCES

AOAC , 1990. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists. Washington, DC.

Anderson-Hafermann, J. C., Y. Zhang, and C. M. Parsons. 1992. Effect of Heating on Nutritional Quality of Conventional and Kunitz Trypsin Inhibitor-free Soybeans. Poultry Sci. 71:1700-1709.

Anderson-Hafermann, J. C., Y. Zhang, and C. M. Parsons. 1993. Effects of processing on the nutritional quality of canola meal. Poultry Sci. 72:326-333.

Mustafa, A.F., D.A. Christensen, J.J. Mckinnon and R.W. Newkirk, 2000. Effects of stage of processing of canola seed on chemical composition and in vitro protein degradability of canola meal and intermediate products. Can. J. Anim. Sci. 80:211-214.

Parsons, C. M., K. Hasimoto, K. J. Wedekind, and D. H. Baker. 1991. Soybean protein solubility in potassium hydroxide: an in vitro test of in vivo protein quality. J. Anim. Sci. 69:2671-3084.

Pastuszewska, B., L. Buraczewska, A. Ochtabinska, and S. Buraczewski. 1998. Protein solubility as an indicator of overheating rapeseed oilmeal and cake. J. Anim. Feed Sci. 7:73-82.

SAS Institute, 1989. *SAS/STAT User's Guide*. Cary, NC: SAS Institute Inc.

PROTEIN DISPERSABILITY INDEX AS AN IDICATOR OF AMINO ACID DIGESTIBLITY IN COMMERCIAL CANOLA MEAL SAMPLES

INTRODUCTION

The digestibility of canola meal can be highly variable and is dependent on the processing conditions used to produce the meal. Quality control personnel need a method of assessing meal quality in the laboratory. Similarly, animal nutritionists require a method of determining the digestibility of the meals they are formulating diets with. The method must be relatively quick, simple and able to consistently predict digestibility. One such proposed method is protein dispersability (PDI). It is a commonly used assay in food production to indicate how much of the protein can be suspended in water (Traina and Breene, 1994). Batal et al., 2000 reported that PDI could be used to determine if soybean meal had been adequately processed and that it was a better predictor than protein solubility. Therefore the objective of this study was to examine the potential of using PDI of processed canola meal as an indicator of amino acid digestibility in canola meal.

MATERIALS AND METHODS

Thirty one commercial canola meal samples collected in 1998 and 21 canola meal samples collected in 2001 were analysed for apparent ileal amino acid digestibility as described earlier in this report. The meals were analysed for PDI using the method as described by Batal et al, 2000. Amino acid digestibility and content were correlated with PDI using the regression analysis function with in Microsoft Windows Excel 2002.

RESULTS AND DISCUSSION

As expected, there was a broad range of PDI values for the canola meals tested both in the 1998 and 2001 samples tested (Figures 1 and 2, respectively). Since PDI decreases with increased exposure to heat (Qin et al, 1998), the range of values observed in this study suggests that the meals were exposed to a wide variety of processing conditions.

PDI was correlated with apparent lysine digestibility in both samples from 1998 and 2001 (figures 1 and 2, respectively). However, the fit to the line in both cases was poor. Samples from 1998 were chosen because they provided a wider range of digestibility values than those from 2001, but unexpectedly the data fit the line better in the narrower data set. Normally one would expect a greater range of values would result in a regression line with a greater predictive capacity, however, it appears in this case that the more overcooked the samples the less predictable the outcome. The samples from 2001 (Figure 2) appeared to have a bimodal distribution. As a result, samples with a PDI of ~ 15% had lysine digestibility values that ranged from 73 to 78% and samples with a PDI value of ~21 ranged in digestibility from 78 to 84%. This would suggest that PDI would only be able to determine if the samples had above or below average lysine digestibility and not the exact values.

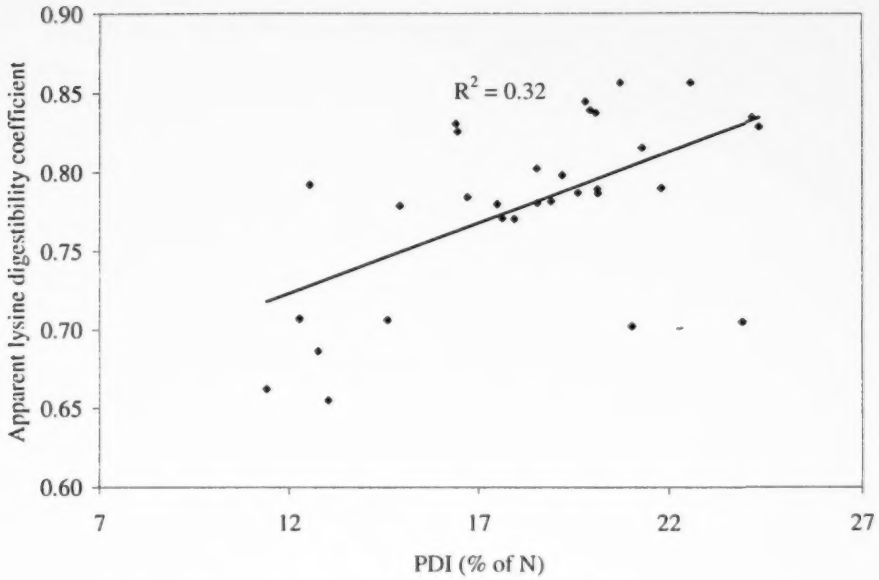

Figure 1. Protein Dispersibility Index (PDI) versus apparent ileal lysine digestibility in canola meal samples collected in 1998.

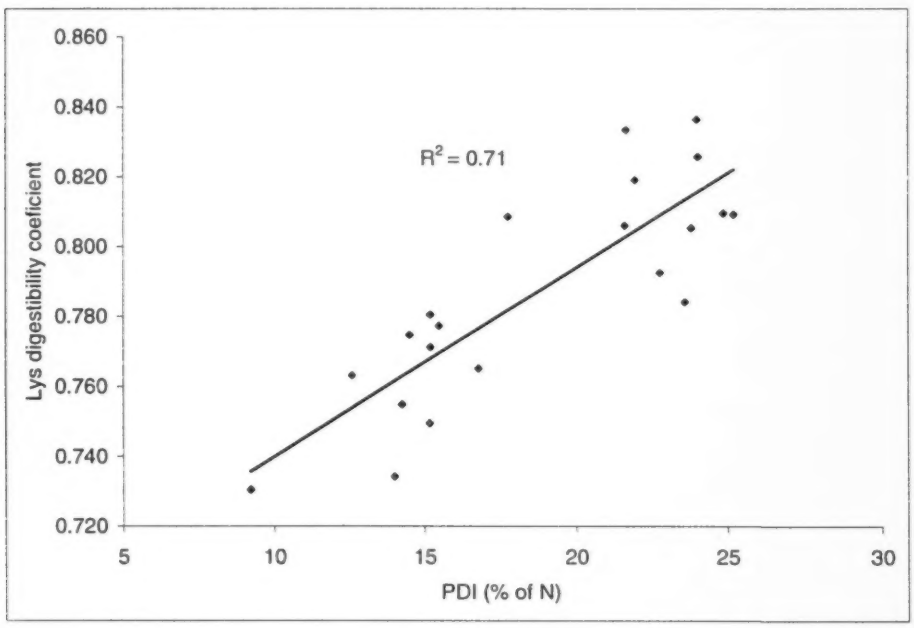

Figure 2. Protein Dispersibility Index (PDI) versus apparent ileal lysine digestibility in canola meal samples collected in 2001.

In previous studies (Newkirk et al 2002), cysteine digestibility in canola meal has been shown to be highly variable. Therefore, PDI was also tested as a predictor of apparent cysteine digestibility. Cysteine digestibility was positively correlated with PDI (Figure 3) but like lysine digestibility, the fit to the line was relatively poor. Therefore, PDI values can be used to indicate if the meal is of poor or high quality but the exact digestibility value can not be predicted based on this assay.

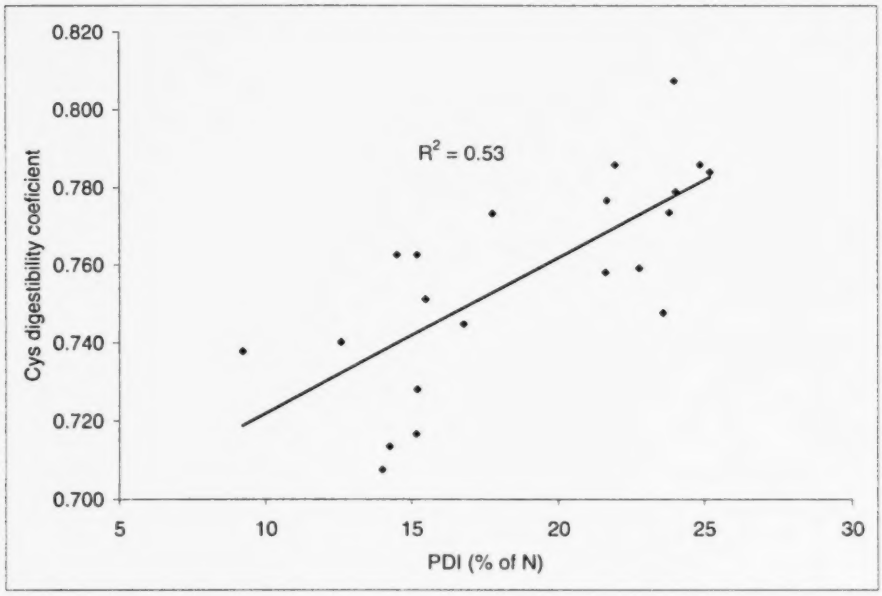

Figure 3. Protein Dispersibility Index (PDI) versus apparent ileal cysteine digestibility in canola meal samples collected in 2001

Not only does processing reduce digestibility of canola meal, but also content. Therefore, PDI was examined for the potential of predicting the digestible content of lysine and cysteine. There was a significant positive correlation between PDI value and digestible lysine content in the canola meal samples from 1998 and 2001 (figures 4 and 5, respectively). However, the fit to the line was relatively poor in both cases. As observed with lysine digestibility, the values from 2000 produced a higher R^2 value than those from 1998. Although PDI was correlated with digestible lysine content, it could only be used as an indication of meal quality and not the exact value for use in diet formulation.

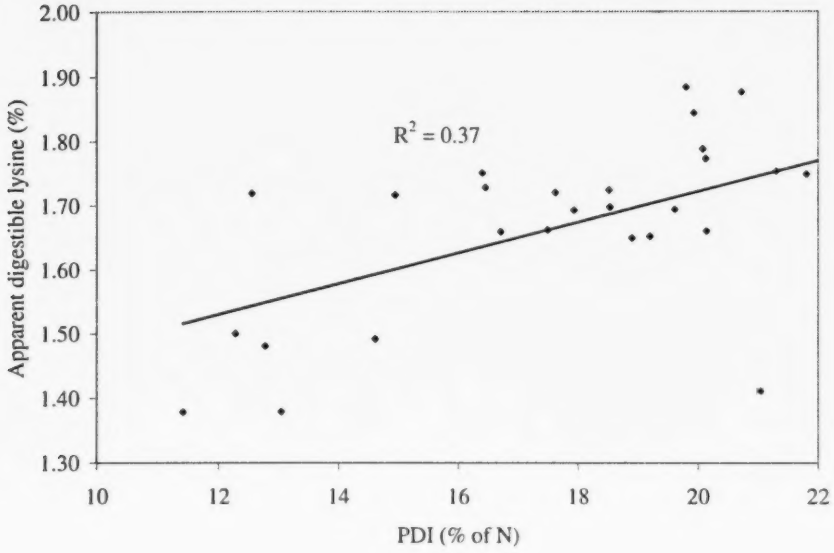

Figure 4. Protein Dispersibility Index (PDI) versus apparent digestible lysine content in canola meal samples collected in 1998.

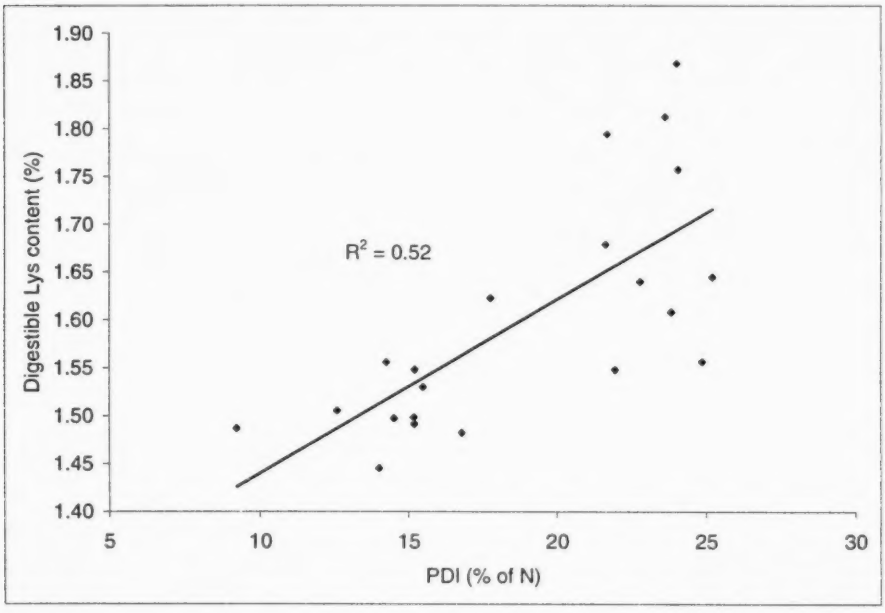

Figure 5. Protein Dispersibility Index (PDI) versus apparent digestible lysine content in canola meal samples collected in 2000.

Digestible cysteine content was positively correlated with PDI value in canola meal (Figure 6). Although, the R2 was still relatively low (0.64) the fit to the line was reasonable and would provide an estimate of digestible cysteine content in the meal.

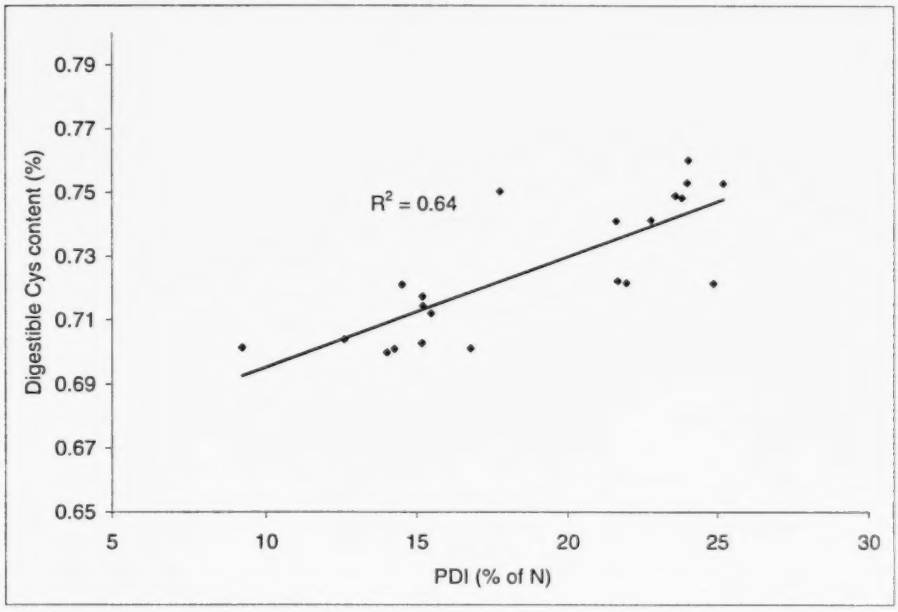

Figure 6. Protein Dispersibility Index (PDI)versus apparent digestible cysteine content in canola meal samples collected in 2000.

CONCLUSIONS

PDI is correlated with lysine and cysteine digestibility and digestible content but the equation line is too poor to accurately predict values for diet formulation. Samples with very low digestibility tend to fit the line the poorest suggesting that the assay is not suitable for overly processed meals. The prediction equation for digestible lysine content (%) = 1.26 + 0.818*PDI (R^2=0.52) and for digestible cysteine 0.66 + 0.0035*PDI (R^2=0.64).

THE EFFECT OF TEMPERATURE, DURATION AND MOISTURE DURING THE TOASTING ON COLOR AND THE LEVEL OF NDIN AND AMINO ACIDS IN CANOLA MEAL

INTRODUCTION

Canola meal is used as a source of protein in the diets of most animals. It has an excellent balance of amino acids, but, during desolventization/toasting the availability and content of amino acids is reduced. In addition, desolventization/toasting changes the color of the meal light yellow color with black flecks of hull to a brown color. The change in color and lysine content is likely the result of Maillard reactions which produce brown pigments. It appears that the direct injection of sparge steam during desolventization may be responsible for promoting the Maillard reactions as suspending it's use produces a meal of light yellow color. Desolventization of the meal after solvent extraction requires the application of heat, but at low moisture content, the Maillard reaction proceeds at a much reduced rate. Direct injection of sparge steam increases the moisture content of the meal as the steam condenses and it is hypothesized that the increase in moisture content during heating is promoting Maillard reactions and therefore responsible for the losses during processing. The effects of temperature, duration and moisture content during processing on Maillard reactions are known for food products but it has not been defined for Canola meal. Production of the highest quality canola meals requires an understanding of which conditions preserve the quality of the product and which ones should be avoided.

Amino acid content, especially lysine, is reduced during advanced Maillard reactions and therefore can be used to assess the effects of processing conditions on the nutritional value of meal. However, the early Maillard reaction products can reduce amino acid availability but not content so just monitoring meal content can underestimate the impact of processing on meal quality. Apparent digestible lysine content decreases linearly with increased neutral detergent insoluble nitrogen (NDIN) as a result of processing. Therefore NDIN is a good indicator of the effects of processing on the nutritional value of canola meal. Advanced Maillard reactions result in a browning of products and therefore the degree to which these reactions are occurring during processing can be assessed by the colour of the meal.

The objective of the first experiment was to determine the effect of temperature and exposure time to direct steam heat on the NDIN content of meal from 2 species of Brassica. The objective of the second experiment was to assess the effects time and duration under specific controlled moisture levels, on the level of NDIN and amino acids in canola meal.

MATERIALS AND METHODS

Experiment 1 – Effect of time and temperature with steam injection

Two samples of seed grade canola, *Brassica napus* variety "Bounty" and *Brassica rapa* variety "Klondike" which were expelled in a lab screw press (Komet Oil Expeller, IBG Monforts Gmbh and Co., Mönchengladback, Post fach 20 08 53, D-41, Germany) and extracted with hexane over a period of 4 h. The meal was desolventized in a fume hood for 2 to 3 d. Samples, 12 g, of the meal were then placed in a folded 18.5 cm Fisherbrand® P8course filter paper (Fisher Scientific, Pittsburgh, PA, 15275) the edges were folded and stapled an envelop approximately 1 cm thick, 8 cm high and 17 cm long. Envelops of meal were then placed vertically in steel racks such that the steam entering the autoclave could penetrate into the meal. The meal was treated in a 2*8*4 factorial design (2 species * 8 processing temperatures, 85, 90, 95, 100, 105, 110, 115, 120°C * 4 durations, 15, 30, 45 and 60 minutes) in an Amsco Eagle Series 2322 Isothermal Autoclave (51 International Blvd., Etobicoke, ON, M9W 6H3). The samples were then dried at 50°C in a forced air oven.

NDIN content of the canola meal samples was determined in duplicate using an Ankom 200 Fiber Analyzer[1]. Canola meal (0.5 g) ground to pass through a 0.5 mm screen was weighed in to Filter bags (Ankom Technology[10], F57) and heat sealed. The filter bags (20), neutral detergent solution (2 l, Ankom Technology[10], premixed chemical solution- FND20) and 1.36 million modified Wohlgemuth Units of heat stable amalyase (Ankom Technology[10], FAA) were added to the analyzer and allowed to agitate for 60 minutes at 100°C. The solution was then drained from the analyzer and washed with an additional 2 l of hot (90-100°C) distilled water with agitation for 5 minutes, this wash procedure was repeated three times. The water was gently squeezed out of the filter bags by hand prior to soaking in acetone for 3 minutes. The acetone was allowed to evaporate prior to drying the bags in an oven at 105°C for 4 hours. The protein content of the meal and the residue in the filter bags were then analysed according to the methods of the Association of Official Analytical Chemists (1990) using the Kjeldahl method. NDIN was then expressed as the proportion of the protein in the meal remaining in the NDF residue.

Experiment 2- Effect of moisture level during toasting

In experiment 1, moisture content of the meal during heating was not directly controlled but moisture content may be directly influence the level of protein damage during heating. Therefore a second experiment was conducted to examine the effects of heating at controlled moisture levels on the NDIN, amino acid content and color of the resulting meals.

Commercially prepress/solvent extracted canola was collected prior to entering the desolventizer/toaster. The meal was placed in burlap sacks and allowed to air desolventize at 20°C over a 72 hour period. The meal was then ground through a 6.0 mm

[1]Ankom Technology Coporation, 140 Turk Hill Park, Fairport, NY, 14450

screen with a Retsch SM 2000 Forage grinder[2]. The moisture content was adjusted by adding the appropriate amount of water to 1.5 kg of meal and mixing with a stainless steel wire whisk prior to placing 50 g in 600 ml glass jars and sealing with a lid. The moisture content of the extracted, air desolventized, ground meal was 7%. The experiment was a 4*4 factorial with four moisture levels (7, 10, 14 and 18%) and 4 temperatures (100, 105, 110 and 115°C). Temperature of the meal was monitored by a thermometer inserted through a tight fitting hole in the lid of the jars into the meal sample. The oven temperature was initially set 20°C above the desired meal temperature in order to achieve the desired temperature more quickly. Once the meal achieved the desired temperature, the meal was maintained at that temperature for 10 minutes. All treatments were replicated 3 times. Sample analysis was conducted in duplicate except amino acid analysis.

The samples were analysed for crude protein and NDIN as described previously. The meals were analyzed for amino acids using a Beckman[3] amino acid analyzer equipped with a Spheroge 1 IEX anion exchange column, System Gold 126AA solvent module, 508 auto-sampler, 166 detector, ninhydrin 232 post column reactor, Mistral[4] column following hydrolysis using the performic acid oxidation with acid hydrolysis and sodium metabisulfite method as described by Llames and Fontaine (1994, Alternative I). The color of the meals was measured using a Hunter Lab – Miniscan XE[5].

Statistical Analysis

For experiment 1, the data was analysed as 2*4*8 (2 species*4 times* 8 temperatures) factorial using the GLM procedure of the SAS program (SAS Institute, 1989). For experiment 2, the data was analysed as a 4*4 (4 moisture levels*4 temperatures). Differences were considered significant when $P<0.05$. Means separation was conducted using the method of (Duncan, 1955) when significant main effects were observed.

RESULTS

Experiment 1 – Effect of time and temperature of steam heating

There was no effect of processing on NDIN content below 100°C. At higher temperatures, however, NDIN level in meals from both species was increased ($P<0.05$) by heat treatment. *Brassica rapa* had higher levels than *Brassica napus* when heated between 105 and 120 °C (Figure1), in spite of having lower levels prior to heating,

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[2] Retsch GmbH & Co. KG, Rheinische Straße 36, 42781, Haan, Germany

[3] Beckman Instruments, Inc., Fullerton, CA, 92834-3100

[4] Holland Spark, P.O. Box 388, 7800 AJ Emmen, The Netherlands

[5] 11491 Sunset hills Road, Reston, VA, 22090-9902

indicating that *Brassica rapa* is more susceptible to heat damage than *Brassica napus*. After 30, 45 and 60 minutes of heat treatment *Brassica rapa* had higher levels of NDIN than *Brassica napus* (figure 2). There was a significant interaction between processing temperature and time on NDIN content in meals (Figures 3 and 4). Below 100°C, the rate of NDIN formation is slow but at higher temperatures the rate increases exponentially.

Experiment 2 – Effect of moisture, time and temperature during processing

Since moisture level was not controlled in experiment one, but may have an impact on the rate of protein damage by reactions such as the Maillard reaction, experiment two was conducted to determine the effects of moisture and temperature on protein quality. NDIN content in canola meal increased linearly with moisture content during heating (Figure 5). There was a significant interaction between moisture content and temperature on the NDIN content of meal. In the absence of added moisture (7% level), there was very little change in NDIN content with increased processing temperature (Figure 6). However, above 7%, the higher the moisture content, the greater the amount of NDIN formed with increasing temperature.

Another method of assessing the level of Maillard reactions occurring during processing is by changes in color. The meal became a darker black color with increased moisture content as evidenced by the reduced HunterLab L value (Figure 7). However, at the meal treated at the highest moisture content (18%) was not as dark coloured as the meals at 10 and 14% however it was darker than the meal at 7%. Similarly, the meal became a darker red hue (lower HunterLab B value) at 10 and 14% moisture but increased again at 18%. The meal also took on a lighter yellow hue (higher HunterLab A values) at elevated moistures. As a result of becoming a darker black and Red color but lighter yellow the meal took on a brownish appearance with increased moisture content during heat treatment.

There was an interaction between temperature and moisture on HunterLab L values. Meal heated at 7% moisture was the brightest white color (highest HunterLab L values, Figure 7.9) but became darker black with higher temperatures. Meal treated with 14% moisture was the darkest color (lowest HunterLab L values) showing little change with temperature. The meal treated with 18% moisture was darker than the meal treated with 7% moisture but lighter than the meals treated with 10 and 14%. Meals treated with 7, 10 and 14% moisture tended get darker black with increasing temperature, but the 18% treatment became lighter as the temperature increased from 100 to 105°C but got darker as the temperature increased further.

There was an interaction between temperature and moisture on HunterLab A values. At 7% moisture, the intensity of the yellow hues tended to decrease as the temperature increased (lower HunterLab A values, Figure 9). However, at higher moisture contents the meals became a lighter yellow color with increased temperature.

There was an interaction between temperature and moisture on HunterLab B values. At low moisture (7%) the meal became a darker red (lower HunterLab B values) as temperature increased, but at the highest moisture content (18%) the meal became a lighter yellow color as temperature increased from 100 to 105°C but became darker again as the temperature rose from 110 to 115°C. Both the 10% and 14% treatments had darker red colors at all temperatures than the 7 and 18% moisture treatments.

There was a significant effect of moisture level on the content of all the amino acids measured except valine. Amino acid content was reduced as moisture content increased (Table 7.1). Lys content was most adversely affected by moisture content with a 13.3% decrease as the moisture content was increased from 7 to 18%. There was also a significant effect of temperature on the content of ile, leu and lys. The content of ile, leu and val increased while lys content was reduced with increasing temperature (Table 2).

There a significant interaction between moisture and temperature on the content of His, Ile, Leu, Lys, Phe, Thr, Val. At 7% moisture, the content of lys was not affected by temperature, however at 10 and 14% moisture it decreased linearly with increasing temperature (Figure 11). At 18% moisture, Lys content was low at 100°C, increased with temperature up to 110°C, then declined rapidly at 115°C.

The His content tended to be increased by temperature at 7 and 18% moisture, but decreased with at higher temperatures at 10 and 14% moisture. Isoleucine content tended to increase with temperature for all moisture contents except 14% which tended to decrease with rising temperatures. Leu content tended to increase as temperature increased from 100 to 110°C at 7 and 18% moisture but then decreased as the temperature rose to 115°C. The Leu content in the 10 and 14% moisture treatments tended to remain constant between 100 and 110°C but increased at 115°C. Phe content in the 18% treatment tended to increased with temperature, but temperature had no apparent affects in the other treatments. Thr content of the 7% moisture treatment decreased as the temperature rose from 110 to 115°C but there was no effect of temperature at 18% moisture. At 10% moisture, Thr content tended to decline with rising temperature but at 14% moisture it tended to be increased with temperature. Valine concentration increased with temperature at 7, 10 and 18% moisture but tended to decline with rising temperatures at 14% moisture.

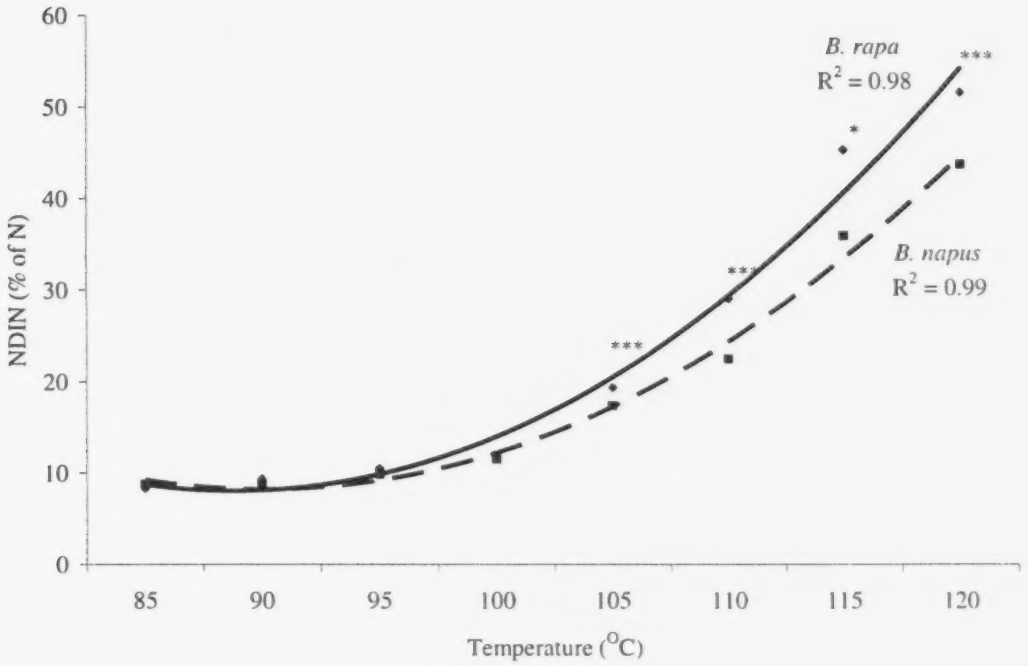

Figure 1. The effect of processing temperature on the NDIN content (as a proportion of N) of *Brassica rapa* and *Brassica napus* meals (data point is average of 15, 30, 45 and 60 minutes heating). Data points with in a temperature with a superscript above them indicate significant differences between species (*, *** denote $P<.0.05$ and $P<0.001$, respectively).

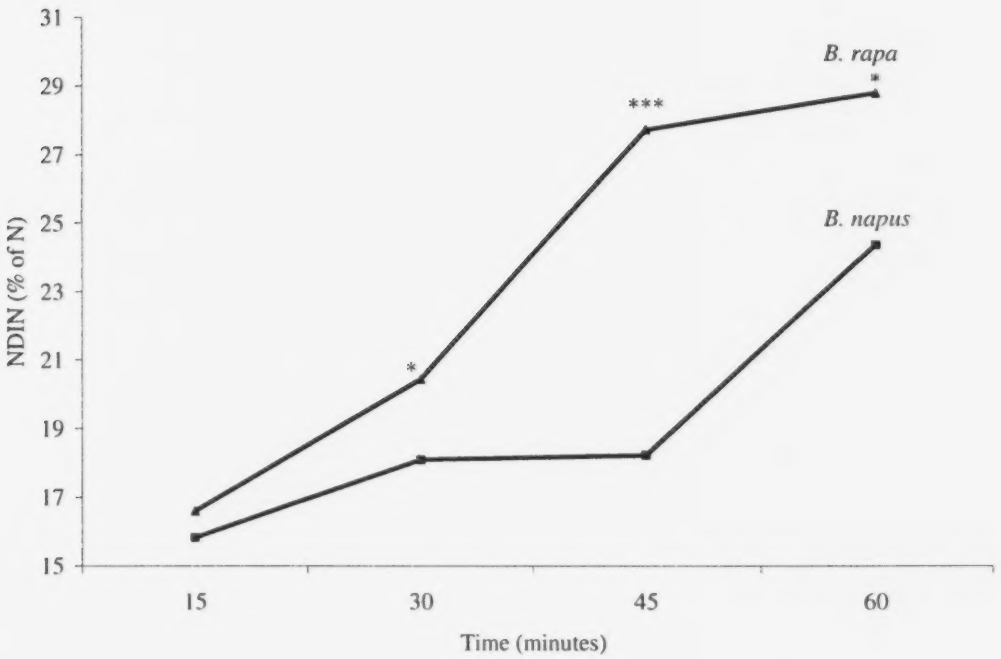

Figure 2. NDIN content of Brassica rapa and napus meals heated for 15, 30, 45 or 60 minutes (average of all temperatures shown). Statistically significant effect of species within time are noted by * (*, *** denotes P<0.05 and 0.001, respectively).

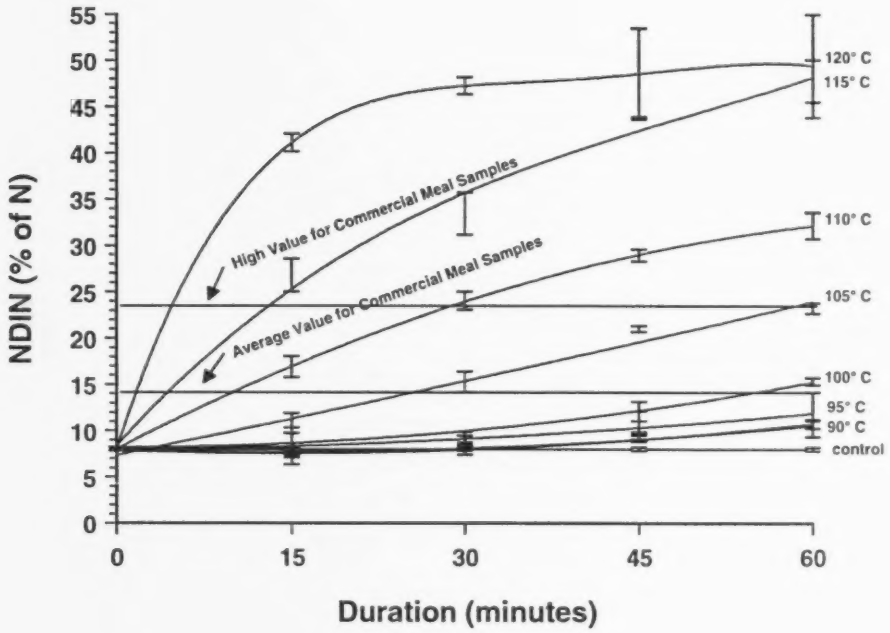

Figure 3. NDIN content (proportion of nitrogen) of *Brassica napus* meal (± standard error) heated in an isothermal autoclave for 0- 60 minutes at 90 - 120°C.

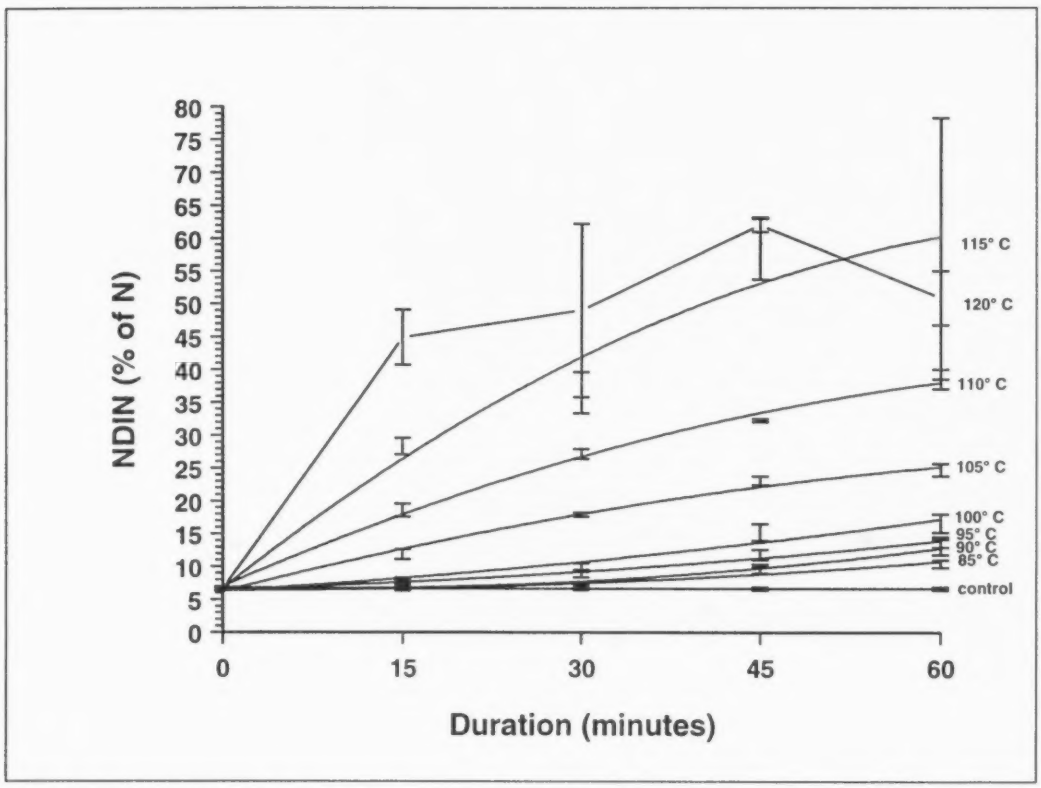

Figure 4. NDIN content (proportion of nitrogen) in *Brassica rapa* canola meal (± standard error) after isothermal autoclaving for 0-60 minutes at 85 - 120°C.

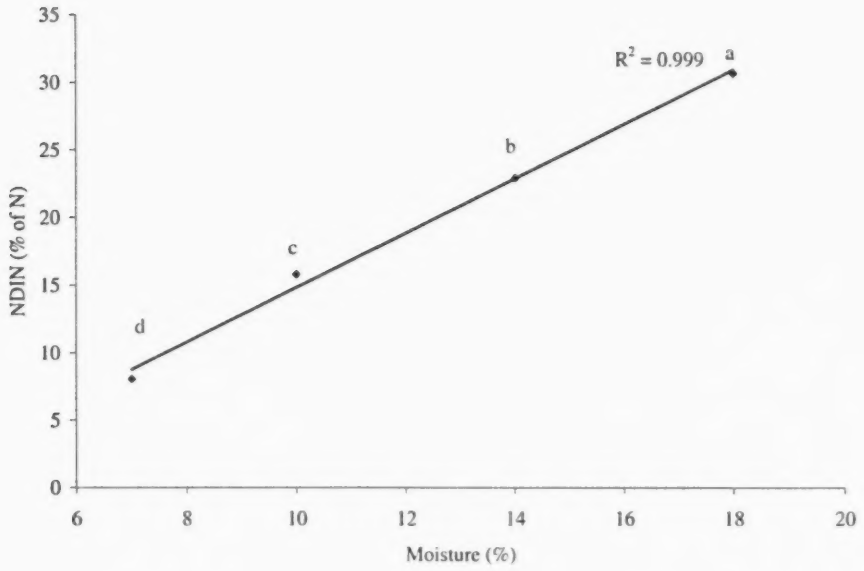

Figure 5. The effects of moisture content during heat treatment on the NDIN content of canola meal. Means without a common letter are significantly different ($P<0.05$).

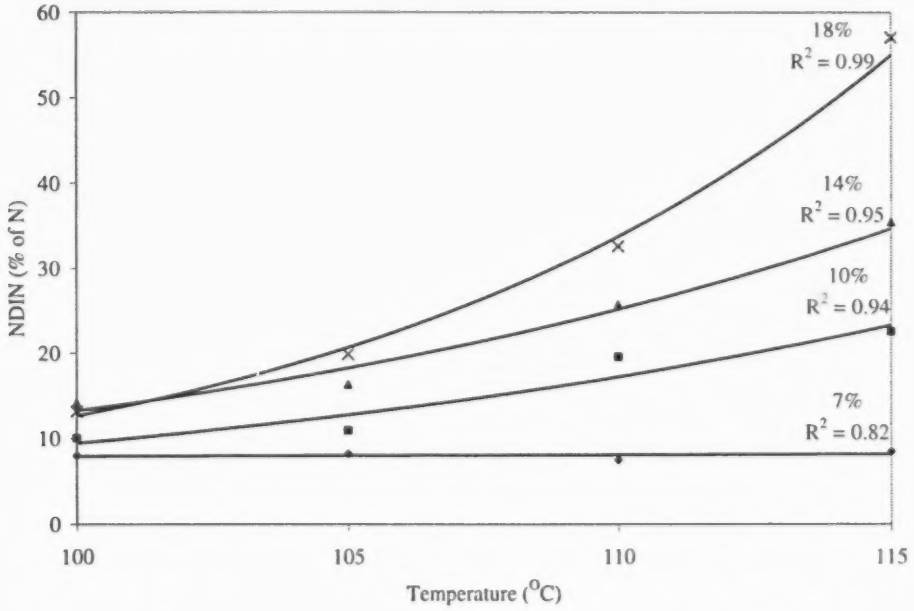

Figure 6, The effect of moisture and temperature on the NDIN content in canola meal after 10 minutes of heating.

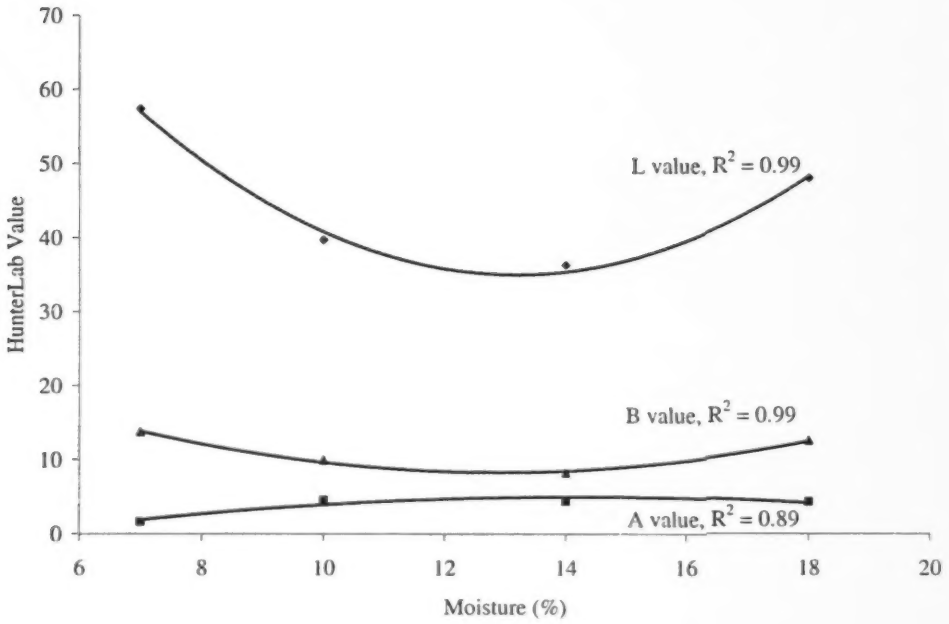

Figure 7. The effect of moisture content during heating for 10 minutes on color of canola meal (Hunter lab – A,B and L values).

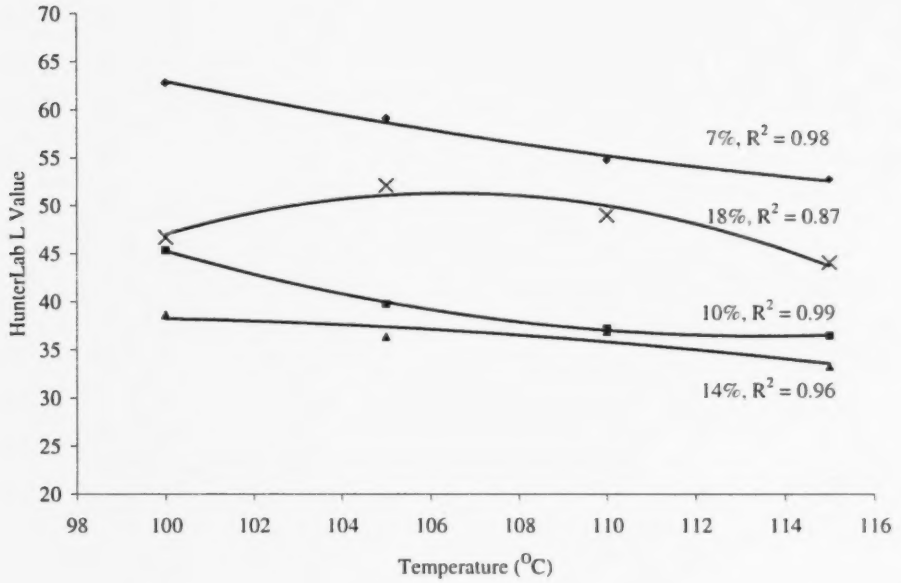

Figure 8. The effect of moisture and temperature on the color (HunterLab L) of canola meal after heating 10 minutes.

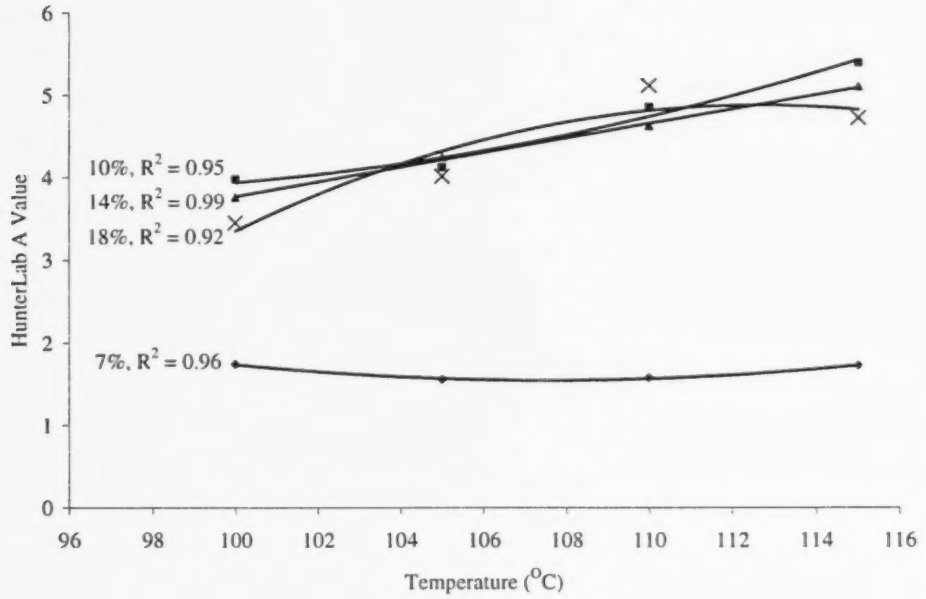

Figure 9. The effect of moisture and temperature on the color (HunterLab A) of canola meal after heat treatment.

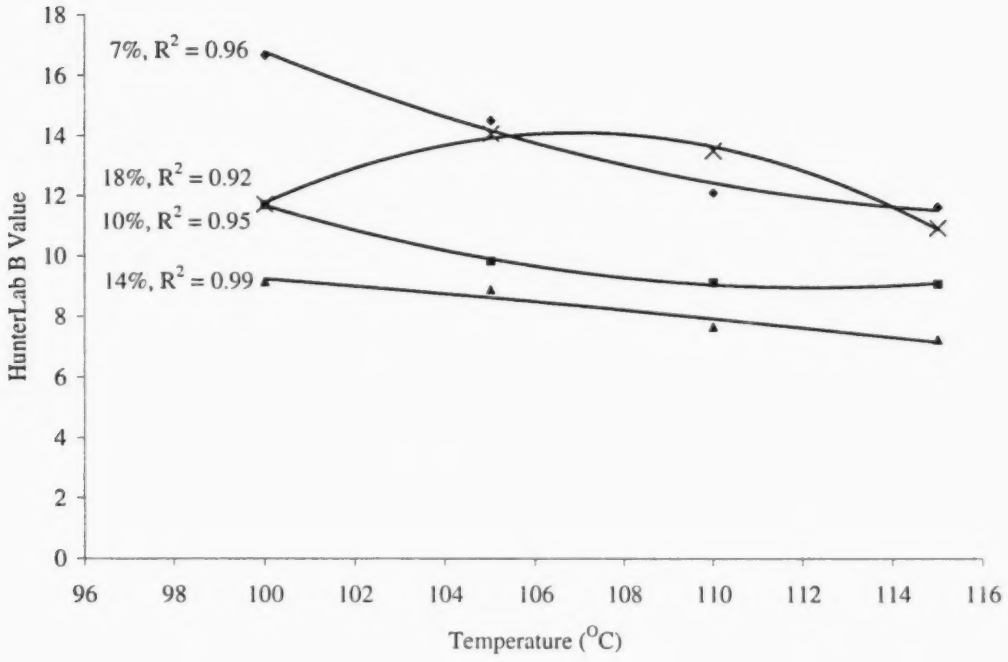

Figure 10. The effect of moisture and temperature on the color (HunterLab B) of canola meal after heat treatment.

TABLE 1. The effect of moisture content of canola meal heated 10 minutes on the amino acid content (% dry matter basis) of canola meal and the probability of the effects of moisture, temperature and an interaction

	Moisture Level (%)					Main Effect		
	7	10	14	18		Moisture	Temperature	Interaction
		(%)			SEM	Probability		
Arg	2.71[a]	2.56[b]	2.51[b]	2.48[b]	0.022	***	NS	NS
Cys	0.94[a]	0.89[b]	0.86[c]	0.88[b]	0.005	***	NS	NS
His	1.13[a]	1.10[b]	1.07[c]	1.04[d]	0.006	***	NS	*
Ile	1.66[a]	1.67[a]	1.62[b]	1.67[a]	0.009	*	*	**
Leu	2.98[a]	2.90[b]	2.86[b]	2.89[b]	0.009	***	*	*
Lys	2.40[a]	2.25[b]	2.15[c]	2.08[c]	0.025	***	***	*
Met	0.79[a]	0.76[b]	0.76[b]	0.75[b]	0.003	***	NS	NS
Phe	1.69[a]	1.66[b]	1.63[c]	1.64[bc]	0.005	***	NS	*
Thr	1.77[a]	1.70[b]	1.73[b]	1.72[b]	0.006	***	NS	*
Val	2.05	2.06	2.02	2.07	0.010	NS	*	***

[a,b,c] Means within a row without a common superscript differ significantly (P<0.05).
*,**,*** Significant at P<0.05, P<0.01, and P<0.001 respectively; NS, non-significant (P>0.05).

TABLE 2. The effect of temperature on the amino acid content (% dry matter) of canola meal after heat treating for 10 minutes

Temperature (°C)	100	105	110	115
		(%)		
Ile	1.63[b]	1.66[ab]	1.65[ab]	1.69[a]
Leu	2.88[b]	2.90[ab]	2.93[a]	2.92[a]
Lys	2.26[a]	2.29[a]	2.22[a]	2.10[b]
Val	2.02[b]	2.04[b]	2.04[b]	2.09[a]

[a,b] Means within a row without a common superscript differ significantly ($P<0.05$).

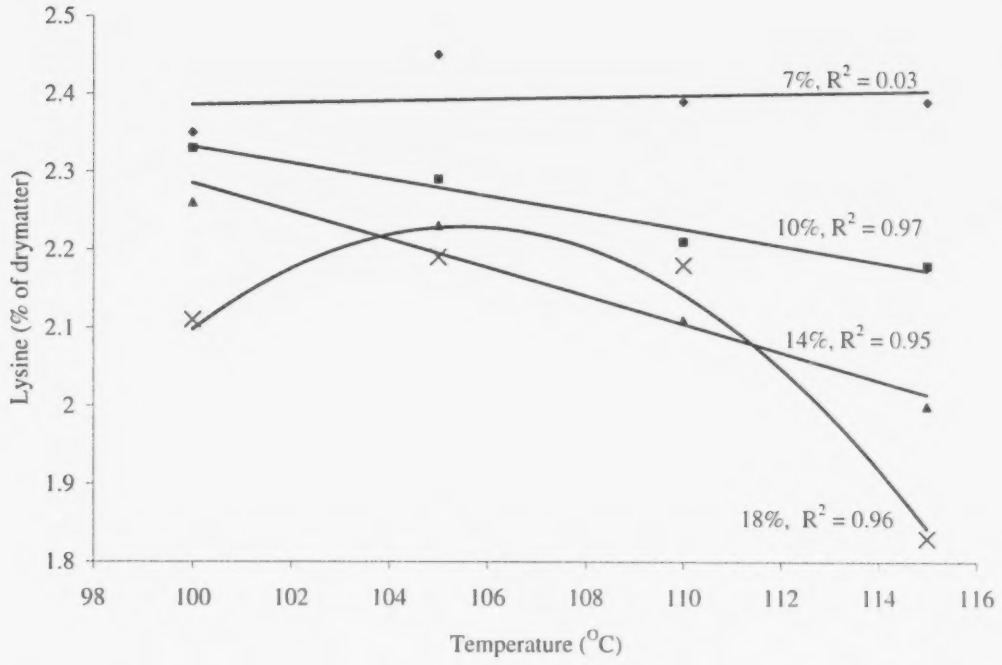

Figure 11. The effect of moisture and temperature on lysine content (% of dry matter) during heat processing of canola meal.

TABLE 3. The effects of moisture and temperature during processing on the content of amino acids in canola meal heated for 10 minutes.

		Moisture (%)			
	°C	7	10	14	18
		(%)			
His	100	1.11	1.13	1.09	1.03
	105	1.13	1.11	1.08	1.04
	110	1.14	1.09	1.04	1.06
	115	1.15	1.08	1.06	1.04
Ile	100	1.60	1.66	1.66	1.59
	105	1.68	1.66	1.63	1.65
	110	1.66	1.71	1.54	1.69
	115	1.71	1.66	1.63	1.74
Leu	100	2.95	2.89	2.86	2.81
	105	3.00	2.88	2.83	2.88
	110	3.00	2.93	2.86	2.91
	115	2.96	2.87	2.97	2.95
Phe	100	1.66	1.66	1.64	1.60
	105	1.71	1.66	1.61	1.63
	110	1.71	1.66	1.62	1.65
	115	1.70	1.65	1.65	1.67
Thr	100	1.77	1.72	1.69	1.71
	105	1.80	1.70	1.71	1.71
	110	1.80	1.68	1.75	1.72
	115	1.71	1.71	1.74	1.72

Val	100	1.97	2.04	2.10	1.99
	105	2.05	2.06	2.05	2.02
	110	2.05	2.10	1.91	2.09
	115	2.13	2.06	2.03	2.16

DISCUSSION

The objectives of the current study were to examine the effects of various conditions under which canola is desolventized/toasted on protein quality and color of canola meal. NDIN was used in this study as an indicator of the quality of protein in canola meal as it is negatively correlated with amino acid availability. The increase in NDIN content with processing temperature, indicates that the protein in canola meal is susceptible damage at temperatures above 100°C and that higher temperatures should be avoided during desolventization if possible. *Brassica rapa* had lower initial levels of NDIN (6.3 versus 8.0%) than *Brassica napus* and this is likely due to the thinner hull of the yellow seed and lower levels of insoluble fibre (Slominski et al., 1999). However, the *Brassica rapa* variety was more susceptible to damage by heat as indicated by the higher levels in the meals treated at 105°C and higher. The reason that the *Brassica rapa* is more susceptible to heat damage than the *Brassica napus* is not known, but one could speculate that the thicker hull encapsulates and protects some of the protein from exposure to the heat and moisture. The rate of NDIN formation was also higher in the *Brassica rapa* (Figure 2) which would tend to support this hypothesis.

The formation of NDIN was slow in both species however when the temperature was below 100°C which might be explained by the fact that the Maillard reaction is not as rapid below 100°C as above (Hurrell, 1984).

Commercially, meal is in the desolventizer/toaster for up to 1 hour, but the temperature is not constant during that period. When the meal enters the desolventizer/toaster it is approximately 30% hexane which is heated by indirect heat. The temperature of the meal rises, but is counteracted by evaporative cooling as the hexane boils at approximately 55°C. The meal is constantly being agitated so the meal is only in contact with the plate for short periods of time allowing the meal to cool as the hexane evaporates. By the time the meal reaches the last two plates, most of the hexane has evaporated and therefore the evaporative cooling is no longer a factor. In addition, direct steam is injected into the meal in the last two plates applying a constant source of heat to all the meal as well as increasing the moisture content. The meal is heated to

approximately 105 to 110°C and resides approximately 10-15 minutes in this area. In a previous study (Section 2) the NDIN content of commercial meals was determined and is shown in figure 3. Autoclaving at 105 to 110°C for approximately 10 minutes produces a meal from *Brassica napus* that is similar to commercially produced meals, suggesting the conditions in the isothermal autoclave approximate the conditions in the final stages of the desolventizer/toaster.

Although the isothermal autoclave method approximates the conditions in the desolventizer toaster, there is no control on the level of moisture incorporated and it may have a direct and significant impact on the degree of protein damage as moisture is required for the Maillard reactions (Mauron et al., 1981). In this experiment it was not possible to control the level of moisture in the meal during heating but it would be expected to increase with temperature as more steam is injected into the autoclave. The moisture content of the meal exiting the autoclave could not be accurately determined as some of it flashed off as soon as the steam pressure was released and as the samples were exposed to atmospheric air. Therefore it was not possible to isolate the effects of moisture and temperature on meal quality in this experiment. Commercially it is necessary to heat the meal to desolventize it, but there are two ways of providing this heat. It can be transferred indirectly through steam heated trays, and this does not increase the moisture content of the meal as there is no steam to condense in the meal. Or it can be applied directly in the form of steam that is injected directly into the meal but this increases the moisture content of the meal. The moisture content of the meal exiting the desolventizer/toaster is typically 14-18% moisture (Fred Buschau, Cargill Ltd. Personal communication) but it is not known if this is the ideal combination of direct and indirect heat to optimize protein quality. Therefore a second experiment was conducted to assess the effects of moisture and temperature on protein quality after processing. The moisture content of the air desolventized meal used in this study was 7% indicating that if no sparge steam was used during desolventization, one would expect the meal to be 7% or less when exiting the desolventizer toaster.

Four moisture conditions were used in this study, no added water (7%) and 10, 14 an 18%. Since it appears that meal is exposed to the high moisture high temperatures in the desolventizer/toaster for approximately 10 minutes this was the processing time used in Experiment 2. Meal exiting the DT can range in temperature from 100 to 115°C so four temperatures in this range were used in this experiment.

The linear increase in NDIN content with moisture content suggests that addition of moisture during desolventization is detrimental to amino acid availability in canola meal. In the absence of added moisture (7% treatment), NDIN content of the meal was not affected by heating indicating that direct steam injection, and therefore moisture incorporation should be avoided. This is consistent with the conditions that promote Maillard reactions. In a mixture of casein and glucose, no browning is observed at low moisture content but maximal loss of lysine is observed between 15 and 18% moisture (Lea and Hannan, 1949).

Higher temperatures, in the presence of added moisture also promote additional protein damage which is likely the result of increased rate of Maillard reactions (Martins et al., 2001). Therefore, if direct heat must be used to desolventize the meal and therefore the moisture content is increased, it would be advisable to use the lowest possible temperatures. However, if no additional moisture is added to the meal during desolventization temperatures of up to 115°C for 10 minutes can be tolerated with little effect on the meal.

Color can also be an indicator of the amount of browning that has occurred during processing (Mauron, 1981). The meals heated with added moisture were a noticeably darker brown color. One method of assessing the color of products is with the HunterLab color system. The HunterLab system measures the color and intensity of reflected light and reports it in a three dimensional manner. The L value indicated how light coloured a product is. A L value of 100 indicates the product is pure white, while a L value of 0 indicates the product is straight black. The A value determines how red or green a product is, the more positive the value the closer the product is to red, the more negative the number the closer the product is to green. The B value indicates how yellow or blue a product is, the more positive, the more yellow, the more negative, the closer to blue the product is. Similar to NDIN values, heating the product at 7% moisture had little effect on the color of the meal indicating that the Maillard reactions are likely inhibited. However, heating in the presence of added moisture resulted in a darker, more red, less yellow color which would be consistent with the formation of brown pigments as a result of Maillard reactions. This also suggests that the losses in amino acid content and availability are at least partially attributable to Maillard reactions.

However, unlike NDIN content, the color became lighter as the moisture content was increased from 14 to 18%. The Maillard reaction requires water but too much moisture inhibits the dehydration steps involved in the advanced reactions that lead to the formation of melanoidins (Lea and Hannan, 1949). However, the early and intermediate stage Maillard products that lack color are indigestible (Mauron, 1981) and therefore color is not an accurate method of assessing amino acid availability. For example increasing the moisture content to 18% during processing will lead to a lighter coloured meal giving the appearance of a better quality meal, but the NDIN content will be higher and the digestibility will likely be lower than that of a darker coloured meal produced at 14% moisture.

As would be expected based on the kinetics of the Maillard reaction (Lea and Hannan, 1949), the meal became darker in color (HunterLab L) at higher temperatures. However at 18% moisture, there was little effect of temperature on the color further indicating that the advanced Maillard reactions responsible for the formation of dark colour is impaired at this level of water.

As with NDIN and colour, amino acid content was not affected in the absence of added moisture further suggesting the addition of moisture through direct sparge steam injection should be avoided if possible. Lysine content was most adversely affected by heat treatment at elevated moisture content, which is consistent with the hypothesis that

the Maillard reaction is responsible for the loss in protein quality as the ε-amino group in lysine is most susceptible to reactions with aldose sugars (Martins et al., 2001). However, the other amino acids are also susceptible when they are the terminal α-amino acid or when they react with intermediary Maillard products such as hydrosyxymethyfurfural or furfural to form aldimines or ketimes. It is unlikely that the amino acids undergo strecker degradation as this Maillard reaction usually occurs as alkaline pH and canola meal used in this study had a pH of 5.9. Similarly it is unlikely that the amino acids reacted with fission products such as acetol or diacetyl to form aldimines or ketimes as this is also promoted by alkaline pH (Martins et al., 2001).

At the highest moisture content, amino acid content was reduced by heating but the effect of increasing temperature was not as consistent as found at lower moisture contents. This might suggest that the moisture level, rather than temperature is the rate limiting factor at that point.

CONCLUSIONS AND IMPLICATIONS

Processing temperature, duration and moisture content affect the amount of protein damaged in canola meal during desolvenitization/toasting. Iso-thermal autoclaving approximate the conditions found commercially in the final stages of desolventization/toasting but do not allow control of the proportions of direct and indirect heat applied to the meal. *Brassica rapa* prior to heating has a lower proportion of NDIN than *Brassica napus*, indicating it's amino acid availability is higher, but it appears to be more sensitive to heat treatment. Direct heat, the injection of steam directly into the meal, increases the moisture content of the meal during heating as a result of condensation. In the absence of added moisture, the meal does not change color, loss amino acid content or quality. However, increasing the moisture content as occurs with direct sparge steam heating, promotes the Maillard reactions and therefore losses in amino acid content, availability and changes the color of the meal to a brown color. High levels of moisture (18%) appears to impair the advanced Maillard reactions responsible for the formation of brown colors and produces a meal of lighter color than if heated at 10 or 14% moisture. However, in spite of the lighter brown color, amino acid availability as predicted by NDIN content is lower than those meals produced at 10 or 14% moisture. Therefore the color of canola meal is likely a poor indicator of meal quality after processing. If possible, the use of direct sparge steam during desolventization of canola meal should be avoided. If it must be used to effectively desolventize the meal, the amount of direct steam injection and the temperature and duration should be minimized to produce the highest quality canola meal.

REFERENCES

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11:1-42.

Hurrell, R. F. 1984. Reactions of food proteins during processing and storage and their nutritional consequences. Developments in Food Proteins 3.

Lea, C. H. and R. S. Hannan. 1949. The effect of activity of water, of pH and of temperature on the primary reaction between casein and glucose. Biochem. Biophys. Acta. 3:313-325.

Martins, S. I. F. S., W. M. F. Jogen, and M. A. J. S. van Boekel. 2001. A review of Maillard reaction in food and implications to kinetic modelling. Trends Food Sci. Tech. 11:364-373.

Mauron, J. 1981. The Maillard reaction in food; a critical review from the nutritional standpoint. Progress in Food and Nutrition Science 5:5-35.

Mauron, J., R. F. Hurrell, K. J. Carpenter, and J. E. Knipfel. 1981. Maillard reactions in food. Chemical, physiological and technological aspects. Progress in Food and Nutrition Science 5:vii.

SAS Institue. 1989. SAS/STAT User's Guide. SAS Institute Inc., Cary, NC.

Slominski, B. A., J. Simbaya, L. D. Campbell, G. Rakow, and W. Guenter. 1999. Nutritive value for broilers of meals derived from newly developed varieties of yellow-seeded canola. Anim. Feed Sci. Tech.. 78:249-262.

METHODS OF COMMERCIALLY PRODUCING NON-TOASTED CANOLA MEAL

INTRODUCTION

The toasting process reduces the content and digestibility of amino acids in canola meal (Newkirk et al 2002) and it also results in a less consistent product. As discussed in earlier sections of this report, the toasting process is a result of applying high temperature and moisture during the desolventization of the meal. The inconsistent nature of the meal and the reduced digestibility and content of amino acids, is responsible for the reduced value of the meal and the losses of millions of dollars per year to the industry. The objective of this study was to examine methods of commercially producing a non-toasted meal.

MATERIALS AND METHODS

Since added moisture appears to be one of the main factors contributing to the toasting process and losses in value it was decided to find ways of desolventizing the meal without added moisture. The first study was conducted to determine if it is possible to desolventize canola with out sparge steam, the source of added moisture during desolventization. To do this, 1.4 tonnes of solvent extracted meal, but non-desolventized was collected from a commercial crushing plant. The meal was collected from the conveyer that takes the solvent extracted but hexane laden meal from the solvent extractor to the desolventizer toaster. The meal was collected in steel 45 gal drums, sealed and transported to POS Pilot Plant Corp. (Saskatoon, SK, Canada, S7N 2R4) for desolventization studies. The solvent laden meal was then conveyed into in a DT (77.5 cm inside diameter) built by Crown Iron Works (Minneapolis, MN, USA, 55440-1364) equipped with two steam heated trays (53.3 cm between trays). The line for feeding sparge steam into the meal was disconnected such that the meal was desolventized solely by indirect heat in the form of steam heated trays (no added moisture). The rate of flow through the unit was adjusted such that the exit temperature of the meal was approximately 100°C and no residual hexane could be detected.

A second study was conducted to compare desolventization with and without added sparge steam during desolventization. Again solvent extracted, but not desolventized, was collected in 45 gallon drums. The sealed drums were then transported to the Texas A&M University Food Protein Research and Development Center (College Station, Texas, USA, 77843-2476). The solvent laden meal was then conveyed into a 77.5 cm inside diameter DT produced by Crown Iron Works (Minneapolis, MN, USA, 55440-1364). The DT had 3 steam heated trays, and was set such that the canola meal was approximately 15.3 cm deep on each of the trays. The system was heated with 135 PSI steam and temperature of the meal exiting the system was controlled to approximately 100°C. Conventional toasted meal was produced using both indirect heat and sparge

steam to desolventize the meal. Non-toasted meal was produced by turning off the sparge steam and desolventizing by through indirect heat (steam heated trays).

The third phase of the program to determine methods of commercially producing non-toasted meal was to travel to Minneapolis, MN and present the results of our studies to the primary manufacturer of desolventizers in North America (Crown Iron Works Minneapolis, MN, USA, 55440-1364), the author spent time discussing the details of all of the canola processing studies with the engineers at that company. Then a discussion was initiated as how to implement these findings commercially.

RESULTS AND DISCUSSION

Experiment 1- Desolventization without sparge steam at POS

One of the major concerns raised by the commercial canola crushing companies about turning off the sparge steam during desolventization is the potential for increased hexane losses. Sparge steam does effectively transfer heat to meal and therefore reducing sparge steam does decrease the rate of energy delivery into the meal for desolventization. In the first study, conducted at POS Pilot plant, there was three primary objectives. The first was to determine if the elimination of sparge steam will result in the production of non-toasted canola meal. The second and third objectives, however, were to determine how much the desolventization capacity is reduced by eliminating the sparge steam, and to determine the level of residual solvent found in the meals produced in this manner.

The meal produced at POS without added sparge steam was a much lighter color than that found commercially and was therefore considered to be non or lightly toasted. The meal produced had acceptably low hexane levels (256 ppm) and the rate of desolventization was surprisingly fast (128kg/hr). Basically it was found that the DT could handle as much meal as we could physically deliver to the system. Therefore it appeared from this study, that it was possibly to effectively desolventize meal without added sparge steam. Based on these findings, one could suggest that the added heat in the form of sparge steam is simply added heat that causes overheating of the meal. However, before this conclusion could be drawn additional studies are required and for this reason a second study was conducted at another pilot plant.

Experiment 2 – Desolventization with and without sparge steam at Texas A&M

In the second experiment, a much larger volume of material was used for the study; a flat deck semi-trailer loaded with 45 gal steel drums full of hexane laden meal was transported to Texas for desolventization. Initially the unit was run under normal desolventization conditions, to determine the rates of desolventization with sparge steam and to produce a conventional meal for comparison purposes. As expected the system ran well and desolventized 110 kg/hour producing a brown coloured obviously toasted meal, although not as dark as many samples collected commercially by the author. The desolventizer was run under these conditions for 3 days straight to make sure we had good data on the system.

In attempt to produce non-toasted meals, the sparge steam input was shut off during desolventization at the Texas pilot plant. Almost immediately, a change in the color of the meal was observed, the meal was a much lighter color tending more to a yellowish color than the brown color observed with normal desolventization. The desolventizer was run for 5 days under these conditions to get reliable data on desolventization capacity. In the absence of sparge steam the capacity of the system was 122 kg/hr, 12 kg/hr higher than observed for the toasted meal. It would seem unreasonable, based on theories of heat transfer, that desolventization rates would increase without added sparge steam, but it can be concluded that desolventization rates were definitely not reduced.

One of the difficulties in applying pilot plant data to commercial scale crushing plants is not direct. Therefore, one has to rely on the expertise and experience of the manufacturers of the systems to determine if the findings in the pilot plant can be directly applied to the commercial systems. Therefore, the author met with the engineers from the company that made the pilot equipment and also produced the majority of the commercial systems currently being used – Crown Iron Works in Minneapolis MN.

Discussions with Crown Iron Works Engineers

The author spent the day at the Crown Iron Works plant discussing the findings of this research. The meetings were well attended by Crown Iron Works staff and there seemed to be a keen interest in the subject matter. The audience ranged from the vice president of North American production, the engineer in charge of DT design and installation, pilot plant staff and operational consultants. The author presented the findings of reduced meal quality and value during commercial canola meal desolventization and results of in-vitro studies on the effects of time, temperature and moisture on meal quality. Then there were open discussions regarding how to retrofit existing systems to produce a non-toasted meal.

The first comments from the staff of Crown were regarding the history of the DT and why it is configured the way it is. It became very clear from the discussions that the DT was designed for Soybean and has been directly adapted to canola. Soybean meal has a specific requirement for the toasting process, reduction of trypsin inhibitors and lectins, so is designed to heat the meal over and above that required for desolventization. However, the system is specifically designed to "toast" the meal during the desolventization process. Since it was not known if or how much canola needed to be toasted, the system may not have been optimized. Since canola is a soft seed (contains twice as much oil as soybean) the level of solvent in the meal is greater than found in soybean, so the size of the DT was based on twice the needs of soybean. For example a DT designed for 2000 T/day of soybean meal is only considered to have a capacity of 1000 T/day of canola. Therefore the residence time for canola meal is approximately double that of soybean meal and is therefore toasted to a greater degree. The staff appreciated our findings and agreed that it would be desirable to reduce the degree of toasting of canola meal.

Another comment made by the Crown staff, was that the DT was designed to have a constant feed rate and that changes to processing rates could have undesirable consequences on meal quality. They indicated that initially the Schumacher DT was designed to have rotary valves so residence time in the system could be controlled, but that the industry thought at the time it was an unnecessary expense. Based on our findings however, it would appear to be beneficial to add rotary valves such that the residence time in the systems could be carefully controlled.

During our discussions regarding the pilot studies, it was determined that the results can not be directly applied to the industry since the commercial units are configured differently than the pilot units and because the bed depth is much greater. The pilot units used in these studies have vents on all the trays so hexane can be pulled off directly, however, the newer design that most plants have adopted only has one vent on the system. This vent is place at the top of the unit and relies on sparge steam from the bottom deck to force the vapours counter current through all the decks above it to reach the vent on the top (Figure 1). Therefore if we were to turn off the sparge steam in the current systems, the residual hexane content in the meals would be very high because the vapours were not driven from the system and diluted by sparge steam. There were a couple of methods of overcoming this problem if we are to produce a non-toasted meal.

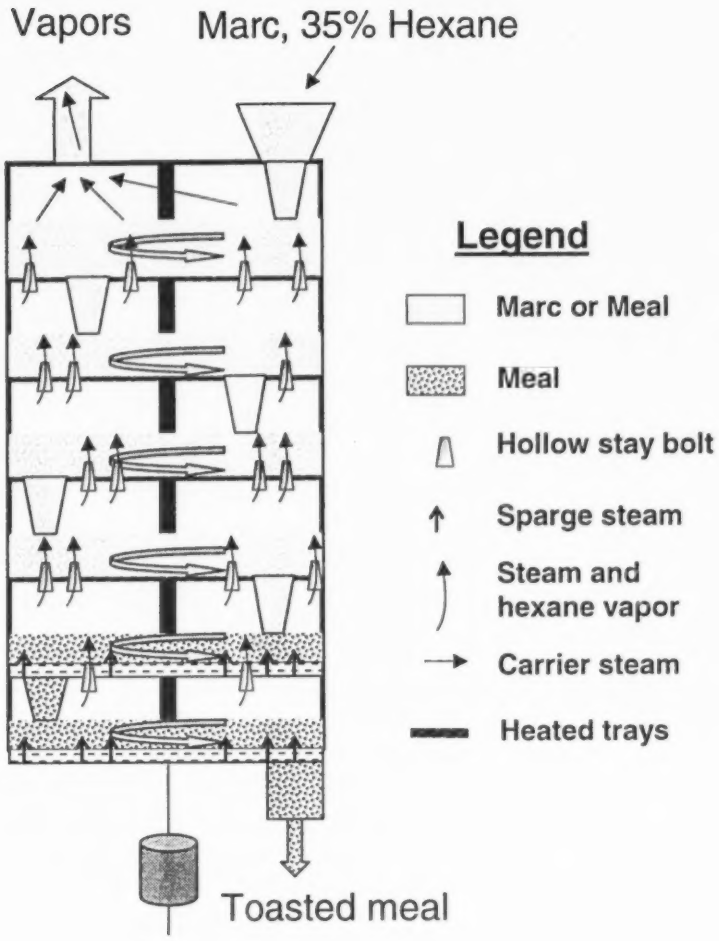

Figure 1. General design of Schumacher desolventizer toasters used in western Canada. Not drawn to scale.

One potential method of producing a non-toasted meal is to use a flash desolventizer. These systems are used by soybean protein isolate plants because it desolventizes at very low temperatures. However, these systems are relatively costly and inefficient and are designed to introduce very little heat during desolventization. Since our findings indicate that is okay to heat the meal to 95-100°C during desolventization, it would not be necessary to add the expense of a flash desolventizer to the system.

Another method discussed for some time, is the application of vacuum during desolventization, in some unpublished work by the author, it was found that canola meal was effectively desolventized if a vacuum is applied during the process. Currently only a

small amount of vacuum is applied to pull the vapours to the condenser. If one increases the amount of vacuum it accomplishes two tasks. One it reduces the boiling point of hexane so desolventization occurs at a lower temperature. But one of the biggest benefits is it increases the migration rate of the hexane out of the material. It is currently believe that sparge steam displaces the hexane in the plant material, thereby increasing migration rate and reducing required time for desolventization. In our earlier studies the largest benefit was in the level of residual hexane found in the meal. With current desolventization methods, especially flash desolventization, there is always residual hexane in the meal, desolventization under strong vacuum very quickly resulted in meals with no detectible levels of residual hexane.

Crown Iron Works has just completed its first commercial installation of a DT with vacuum assisted desolventization. The unit is in a soybean isolate plant is used instead of a flash desolventizer. The system has only been running a very short period of time, but apparently is working well so far. MCN BioProducts Inc. a Saskatchewan based company that is planning on building a plant to produce canola protein concentrates and will likely use this method of producing non-toasted meal for their plant.

Vacuum assisted desolventization appears to be relatively straight forward, but does change the configuration of the solvent recovery systems as well. It would seem to be best suited to places were very low temperatures need to be used such as the production of protein isolates. Another option would be to modify the existing DT systems, such that they have vents on all the trays so the counter current steam flow is required (Figure 2). This would likely be the simplest modifications but should be tested further prior to commercial installation.

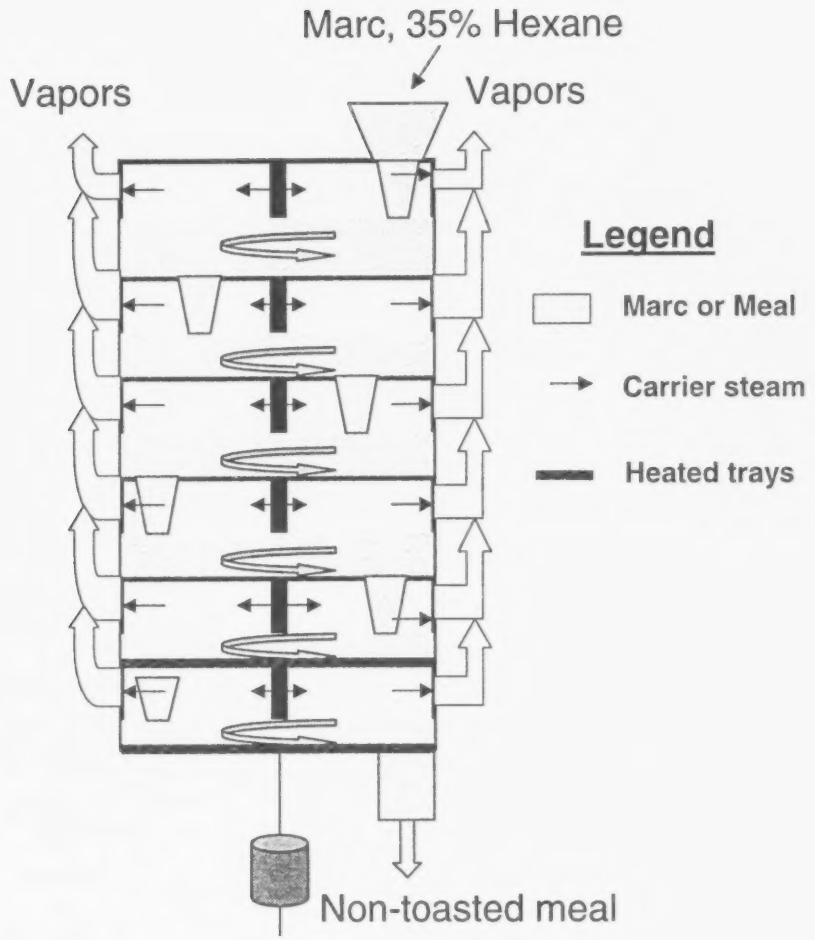

Figure 2 Potential design of a non-toasting desolventizer for canola meal.

Another method suggested was to heated nitrogen to force the vapours counter current through the system, to reduce the boiling point of the hexane and to assist in hexane migration though plant material. This system would require no direct modification to existing DTs but would require significant additions to the plant. The nitrogen would have to be recycled so the major costs of retrofitting would be in the recovery and recycling of the nitrogen. Like the vacuum assisted DT, nitrogen assisted would allow a person to desolventize at much lower temperatures.

Another potential method to produce non-toasted meal is to eliminate solvent from the plants. Until recently, it was not possible to extract canola oil on a commercial scale without solvent. However, Crown Iron Works has just produced its first prototype of a supercritical press. The system uses compressed CO2 to extract the oil, so there is no

need for desolventization. In addition, the process is conducted at 70°C so little heat is applied and the potential for protein damage basically eliminated. This press is a modification of existing expeller presses such that supercritical CO_2 can be pumped through the seed during expelling. Since it is continuous flow, the problems of capacity associated with supercritical extraction are overcome. However, before this technology can be adapted, the system has to be tested and proven for canola, to date only limited studies have been conducted on soybeans.

CONCLUSIONS AND RECCOMENATIONS

The experiments in this study showed that it is possible to effectively desolventize canola meal without toasting it. However, direct application to existing plants is complicated by the need for counter current movement of vapours though the trays and therefore steam injection is required. Currently, plants that require non-toasted soybean meal use flash desolventizers but these are costly, inefficient system and would require the replacement of current desolventizers. Existing systems could be used to produce non-toasted meal if either a vacuum is applied or nitrogen is purged through the system. This would allow the production of meal suitable for the production of protein concentrates but would require modifications to the solvent recovery systems. The most convenient method of producing non-toasted or very lightly toasted meal would appear to be to add vents to each of the decks in the DT and run with out added sparge steam, however, additional studies would be required to ensure plant capacity is not compromised. There appears to be the potential of replacing solvent extraction with supercritical extraction, this would produce a non-toasted meal as well as eliminate the environmental and safety problems associated with the use of hexane. However, further study will be required to examine the feasibility of the use of supercritical phase extraction for canola.

EFFECTS OF TOASTING OF CANOLA MEAL ON DAIRY AND SWINE PERFORMANCE

INTRODUCTION

One of the objectives of this research program was to determine whether toasting of canola meal was required for either reducing the toxicity of canola meal or to improve performance. In a previous section of this report, the effects of toasting on broiler performance. In that study it was determined that toasting had no positive effects on broiler performance and that those birds fed the non-toasted meal outperformed those fed toasted meal. It is assumed that the same effect would be observed in swine but that species tends to be more sensitive to glucosinolate levels than poultry and one of the main potentially positive effects of toasting is the reduction in these goiterogenic compounds. Therefore, it is necessary to test the effect of toasting on the performance of pigs fed canola meal.

One of the largest markets for canola meal is currently the dairy industry. Due to its low protein solubility and high sulphur amino acid content, canola meal is the protein source of choice in many regions but especially in southern California. Since the toasting process is partially responsible for the low protein solubility of canola meal, toasting may be desirable or even preferred for product used in dairy rations. Therefore studies should be conducted to determine if toasting is required for optimal dairy performance.

OBJECTIVES

The objectives of these studies were to determine the effect of toasting of canola meal on the performance of growing pigs and lactating dairy cattle.

MATERIALS AND METHODS

Pre-press solvent extracted canola meal was collected in 45 gallon steel drums from a commercial canola crushing plant prior to desolventization/toasting. The sealed drums (96) were then transported to the Texas A&M University Food Protein Research and Development Center (College Station, Texas, USA, 77843-2476). The solvent laden meal was then conveyed into a 77.5 cm inside diameter DT produced by Crown Iron Works (Minneapolis, MN, USA, 55440-1364). The DT had 3 steam heated trays, and was set such that the canola meal was approximately 15.3 cm deep on each of the trays. The system was heated with 135 PSI steam and temperature of the meal exiting the system was controlled to approximately 100°C. Conventional toasted meal was produced using both indirect heat and sparge steam to desolventize the meal. Non-toasted meal was produced by turning off the sparge steam and desolventizing by through indirect heat (steam heated trays).

RESULTS

The swine study is being conducted in collaboration with Dr. Ruurd Zilstra at the Prairie Swine Centre. Dr. Zilstra has been provided with large enough quantities of toasted and non-toasted canola meals to conduct performance studies with growing pigs. The performance study has not been conducted yet, but is scheduled to begin in the fall of 2002. Since the study is being conducted as a part of Dr. Zilstra's feed ingredient program partially funded by ADF, the research findings will be reported directly to ADF in his progress and final reports.

A milk production study is currently under way in collaboration with Dr. Dave Christensen at the University of Saskatchewan. The author provided large enough quantities of toasted and non-toasted meal that the effects of toasting on milk production in dairy cattle could be determined. That study is almost complete and the results will be reported to ADF in Dr. Christensen's progress report for his strategic research grant. Dr. Christensen is also assessing the rate of protein and dry matter disappearance of canola meals toasted to various degrees. Using *in-vitro* and *in-situ* techniques he will determine how much of the protein is effectively bypass protein and therefore determine if and how much toasting is required to optimize the performance of dairy cattle.

CONCLUSIONS

Since the data is not yet available from the dairy or swine studies no conclusions can be drawn at this time. If it is found that neither species has a specific requirement for toasting, it would be suggested that the industry move to the production of non-toasted meal using one of the methods described earlier in this report. If it is found that one of the species has a specific requirement for toasting it would probably be beneficial to still produce a non-toasted meal, then heat treat the meal in a controlled fashion to provide the level of desired toasting. The current method of desoventizing and toasting simultaneously has the disadvantage of producing very inconsistent levels of toasting. However, if toaster units were set up to provide a constant amount of toasting a more consistent and therefore a higher valued product would be produced.

OVERALL CONCLUSIONS AND DISCUSSION

The first objective of this research program was to monitor canola meal quality. Commercial meal quality was monitored for 2 years and reports sent to the commercial crushers on a routine basis with results and recommendations. Initially meal quality was found to be improving as crushing plants adopted the author's recommendations, however, part way through the study, most plants reduced production levels do to low oil demand and meal quality also suffered. It was generally observed that it is difficult to control the degree of toasting when the plants are running well under design capacity. This is likely the result of extended residence time in the desolventizer/toaster unit. These findings highlight some of the difficulties associated with the production of a consistent toasted canola meal product. Therefore, if plants continue to change production levels on a regular basis and continue to toast canola meal, the desolventizers should be modified so a constant residence time in the desolventizer/toaster is maintained.

A second objective of the research program was to examine methods of predicting digestible amino acid content in canola meal *in-vivo*. Samples from previous surveys as well as samples from the recent surveys were analysed for this purpose. The current protein solubility assay did not predict digestibility or digestible content of amino acids but neutral detergent nitrogen (NDIN) assay did to a certain degree. Protein dispersibility index was correlated with digestible amino acid content, but the fit to the line was relatively poor suggesting it would have limited utility in this application. NIRS was tested and initially showed promise. Additional samples have been analysed are being incorporated into Degussa's program for feed companies. Not all the amino acid analyses have been completed due to the shut down of one of there labs, but preliminary results suggest that NIRS can be used to predict total amino acid content, but the results for digestible amino acid content do not look as promising as in earlier studies. Therefore, NDIN appears to be the best predictor of digestible amino acid content but better assays are still needed.

A third objective of this research program was to examine the causes of toasting and to extablish methods of producing a non-toasted meal. In those studies it was found that moisture was a major contributing factor in the toasting process. At reasonable temperatures (95-105°C), meal was not toasted to any degree if moisture was not added during the desolventization process. Pilot studies with tonne quantities of meal were conducted at POS Pilot plant as well as at Texas A&M pilot plant which confirmed that desolventization without added moisture (sparge steam) results in a non-toasted meal. The data was then provided to the manufacturer of the desolventizer/toasters and methods of producing non-toasted meal was discussed. It was concluded that this could be accomplished in many ways but the simplest would be to either apply vacuum to the system in the place of sparge steam, or add vents to each of the trays, so the vapours do not have to travel counter current through the system. The first DT with vacuum assist has been installed commercially and appears to be working well, but is in a soybean protein isolate plant. The next likely installation will be in a canola protein isolate plant for MCN BioProducts.

A fourth objective of this research program was to examine the effects of feeding non-toasted canola meal to livestock. The first trial was conducted with broiler chickens and showed that there was no need to toast meal for that species. Additional toasted and non-toasted meal has been produced and a Dairy study is currently being conducted at the University of Saskatchewan, and a swine study is scheduled to start soon at the Prairie Swine Center. These studies will determine whether toasting is required for those species and will be reported in the ADF reports prepared by the scientists involved, Dr. Dave Christensen and Dr. Ruurd Zilstra. If there is no benefit to toasting, it will be concluded that the industry should modify their systems and produce a non-toasted meal. If toasting is needed for a single species, it may still be beneficial to produce a non-toasted meal then apply a controlled toasting process to meet the needs of the individual species. Since the full amount of funds applied for were not granted, studies with turkeys and laying hens were eliminated since there was no effect in broilers was observed. The dairy study was added since that industry has a need for insoluble protein and therefore uses a significant portion of the canola meal produced in Canada.

During the production of non-toasted canola meal, that meal heated to low temperatures had an astringent odour. The compound responsible was isolated and identified as 4-pentene nitrile, a breakdown product of 3-butenyl nitrile that if recycling with the hexane used for extraction. This compound and another 41 related compounds were concentrated from a commercial canola crushing plant and fed to broiler chicks. It was found to have no negative effects on animal performance at the levels fed and concluded they should not be an issue during the production of non-toasted meal. Since the compound is the result of toasting and it found in the solvent, if the plants we to eliminate toasting eventually the compounds would decrease due to natural losses. It is not known if there are industrial or agricultural applications for these products, but it would be worth investigating as another potential source of revenue.

All the results have been reported directly to both the feed industries and canola crushing industries and there seems to be an eagerness to adopt the findings. However, in a time of poor margins in the canola industry, they are reluctant to make any upgrades to their systems. The move to the production of non-toasted meal is slower than hoped, but will likely start with production for specific purposes such as the production of protein isolates and after the industry has tried the process will move to full scale production.

4. Personnel

Dr. Rex Newkirk, Ms Marney Korchinski, Ms. Carmen Engleshaan, Ms. Dawn Abbott were paid part or full time out of this ADF grant.

5. Equipment

No equipment has been rented or purchased out of the funds from this ADF grant.

6. Project Developed Materials

There are no project developed material included in this report.

7. Project Photos

There are no project photos to include at this time.

8. Acknowledgement

Funding from ADF was gratefully acknowledged when part of this information was presented at annual meetings of the Poultry Science conference held in Montreal in 2000, Indianapolis in 2001 and Deleware in 2002.. Mr. Newkirk was awarded a Certificate of Excellence for both of his presentations on this material at that time. Acknowledgement of ADF's contributions to this project was also announced when parts of this research was presented to individuals participating in the Canadian Feed Ingredient Program put on by the Canadian International Grains Institute. The Saskatchewan Agriculture and Foods generous support of this research was also acknowledged when Mr. Newkirk presented parts of this material at invited lectures given to the Saskatchewan Canola Growers meeting in December 2000 and at the Western Nutrition Conference in 2000 and 2001. The contributions of Saskatchewan Agriculture and Food was also acknowledged when Dr. Newkirk was interviewed for radio interviews and popular press articles.

9. Expense Statement

A statement of expenses has been forwarded by the University of Saskatchewan.